Studies

on Protein Nutrition of Breeding Sows

by

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A Thesis

Submitted to the University of Edinburgh

in the fulfilment of the requirements

for the degree Doctor of Philosophy.

1976

DECLARATION

This thesis was composed by the writer and is a record of the work carried out by him on an original line of research. All sources of information are shown in the text and listed in the Bibliography and all help given by others is indicated in the acknowledgements.

None of the work recorded here has been presented in any previous application for a degree.

ACKNOWLEDGEMENTS

A very large number of individuals have assisted the author during his studies at the University of Edinburgh. To each is owed a debt of gratitude for their kindness, encouragement, and support. The author is particularly grateful to Professor F.W.H. Elsley who has supervised and advised the author's studies and writing of this thesis, whose help and encouragement is also deeply appreciated. Dr J.P.F. D'Mello has also supervised and advised my studies and writing of this thesis, and I am likewise deeply indebted to him.

I am extremely grateful to members of staff of School of Agriculture who have willingly assisted me on many occasions; in particular to Mr A.G. Taylor, Mr. I. Moffat, and Mr S. Potter.

Thanks are also given to Dr W.J.M. Black and members of his farm staff. Particularly Mr A. Gardoner and the students and staffs who worked in the pig unit, for their help with animal management.

The author is also very grateful to Dr P. McDonald and the members of his department staff, within whose department the work of amino acid analysis was undertaken. I am also very appreciative of Dr P. Crooks and members of his department staff, within whose department the work of milk and nitrogen analysis was undertaken.

The author would like to thank Dr M.F. Fuller and Dr C.T. Whittemore for background advice, support and encouragement.

I am especially indebted to Mr E.A. Hunter and Mr R.H. Fawcett for their advice and invaluable assistance in the statistical analysis of the data of Experiment I.

I am also very grateful to Ajinomoto Inc. (Japan) for donating 20 kg L-tryptophan to my experiment.

The author would like to thank Professor F.K. Koh, Director of Taiwan Pig Research Institute, for his encouragement and offering experimental expenditure. I am also very indebted to Mr W.F, Liu, Manager of Animal Husbandry Department of Animal Industry Research Institute, within whose unit the work of 200-gilt experiment was carried out.

I am deeply indebted to Dr T.P. Yeh for his invaluable encouragement and advice. I would like to thank Mr Y.H. Lee for his advice and invaluable assistance in the statistical analysis of the data of Experiment II by TSC computer programmes.

I also wish to express my sincere thanks to National Science Council of the Republic of China for offering my grants.

Finally, I am very grateful to Miss W. Timms for typing this thesis, and to my wife for her encouragement.

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ABBREVIATIONS

ADG	Average daily gain	µg	Microgram
ARC	Agricultural Research Council	mg	Milligram
CP	Crude protein	g	Gram
DNA	Deoxyribonucleic acid	kg	Kilogram
G/F	Gain per unit feed consumed	µl	Microlitre
NRC	National Research Council	ml	Millilitre
PAAR	Plasma free amino acid ratio	l	Litre
RNA	Ribonucleic acid	µM	Micromole
Mcal	1 megacalorie = 4.19 megajoule	mM	Millimole
		M	Mole
MJ	1 megajoule = 0.239 megacalorie		

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SUMMARY

1. The objectives of this study were (a) to determine the lysine requirement of the lactating sow in order to apply to reduce dietary protein level by improving amino acid balance, (b) the evaluation of the protein and lysine requirements of pregnant sows maintained under commercial conditions, (c) the examination of the results of large scale feeding experiments on pregnant sows given lysine and tryptophan supplementations of a maize diet and (d) the application of the results from detailed experimentation with lactating sows to practical farm conditions and including a large number of animals.

2. In Experiment I during lactation, thirty-six gilts were given the basal diet supplemented with graded levels of lysine up to 0.39, 0.49, 0.59, 0.69 and 0.79% of the diet, and given the high lysine control diet containing 1.06% lysine. The low lysine basal diet supplemented with up to 0.59% dietary lysine improved the amino acid balance and markedly increased pig gains and sow milk production. The energetic efficiency of milk yield and the efficiency of utilisation of dietary protein for milk synthesis increased from 0.39 to 0.59% dietary lysine, and remained fairly constant thereafter. The sows receiving the supplemented diets had considerably higher efficiency of protein conversion into milk protein than those receiving the high lysine control diet. But the sows given the high lysine control diet had a considerably greater energetic efficiency of milk secretion than the sows given the basal diet or supplemented diets.

Nitrogen retention and biological value of the dietary protein increased quadratically with increasing dietary lysine, reaching a maximum at 0.49 to 0.59% lysine in the first two parities. Positive nitrogen balance was observed in sows fed 0.59% lysine in the first parity and those fed 0.49% or more lysine in the second parity.

Apparent digestibilities of isoleucine, lysine, methionine and threonine in the basal diet were closely correlated with digestibility of nitrogen. The level of plasma essential amino acids, except histidine and phenylalanine, reached maximal values 1 h post-feeding, declining rapidly thereafter reaching basal levels 4-16 h post-feeding. Plasma lysine levels remained at a low and constant level at low dietary concentrations of lysine but increased sharply at 0.59% lysine in the diet coinciding with a marked drop in circulating concentrations of other essential amino acids. These responses suggest that the lysine requirement of the lactating sow is 0.58% of a diet containing 12.6 MJ DE/kg. This corresponds to 31 g lysine/day for the lactating gilt and 33 g lysine/day for the lactating sow. If the lysine digestibility of 77% in this study is taken into account, the 'digestible' lysine requirement is 0.49% of the diet.

3. In Experiment II, eight blocks of 25 crossbred gilts were used in a 5 x 5 factorial design to examine the effects of dietary protein concentrations and the supplementation of synthetic amino acids on sow productivity, nitrogen metabolism and plasma metabolite concentrations of breeding sows. The gestation gilts were fed one of the following 5 diets: (1) 9% CP of maize-soybean meal, (2) as 1 + 0.20% L-lysine + 0.05% L-tryptophan, (3) 11% CP of maize-soybean meal, (4) 13% CP of maize-soybean meal, (5) 15% CP of maize-soybean meal. The lactating sows were fed one of the following 5 diets: (1) 12.5% CP of maize-soybean meal, (2) as 1 + 0.20% L-lysine, (3) as 2 + 0.05% DL-methionine, (4) as 3 + 0.025% L-tryptophan, (5) 15% CP of maize-soybean meal.

The quadratic regressions of sow weight gains on daily protein intakes during pregnancy were significant, and indicate that pregnant gilts require a mean of 308 g CP per day to support maximum live-weight gain during pregnancy. The number of pigs born and birth weight were not affected by the dietary treatments in gestation. The pregnant sow given the 9% CP diet had smaller litter size and litter gains at weaning than those given the other diets. The pregnant sow fed the 9% CP diet supplemented by both 0.20% L-lysine and 0.05% L-tryptophan or those offered the 11% CP diet resulted in litter size and litter gains at weaning as good as sows fed higher protein diets. There was an indication of an adverse effect on the interval between weaning and effective service in sows fed the protein diet lower than 13% in the first parity. However, such effects were not apparent in the second parity except for the sows fed the 9% CP diet with both lysine and tryptophan additions.

Daily faecal and urinary N excretion increased linearly as daily protein intakes increased. Supplementation of the 9% CP diet with both lysine and tryptophan increased by 47% the nitrogen retention in pregnancy. This level of nitrogen retention (10.75 g per day) is similar to those of gilts given the 11% CP diet. Although the regression of nitrogen retention on daily nitrogen intake was not quadratic, daily nitrogen retention was only increased slightly as daily protein intake increased from 289 to 315 g. Measured N retention as % of total N intake, pregnant gilts increased protein utilization as dietary protein level increased from 9% to 13%. The 9% CP diet with lysine and tryptophan additions resulted in nitrogen retention as % of total N intake comparable with the 13 and 15% CP diets.

Plasma urea decreased and plasma lysine increased sharply when a 9% CP diet supplemented with both lysine and tryptophan was fed to pregnant gilts. Plasma lysine remained at a low and steady level from those pregnant gilts fed the 9% CP diet (0.28% dietary lysine) up to the 11% diet (0.40% dietary lysine), and increased sharply thereafter.

Based on optimal sow productivity, adequate nitrogen retention, and plasma urea and lysine responses, it suggests that an 11% CP diet containing 0.44% lysine is required for the pregnant sow given 2.0 kg diet per day. A 9% CP diet (maize based) with both 0.2% L-lysine and 0.05% L-tryptophan additions is also adequate for the pregnant sow.

There was no evidence of significant lactation treatment effects on the performance of sow productivity. Supplementing the basal diet with methionine or with methionine and tryptophan after ensuring lysine adequacy had no further improvement in litter gains as compared with the basal diet added lysine.

The basal diet supplemented with lysine increased nitrogen retention and nitrogen retained as % of total N intake. Supplementing the basal diet with methionine or with methionine and tryptophan after providing lysine adequacy had no further increases in nitrogen retention and nitrogen retained as % of total N intake. Plasma lysine increased sharply as the basal diet with lysine additions. Based on optimal sow productivity, nitrogen balance, and plasma lysine criteria, it indicates that a value of 32 g lysine is required for the lactating sow fed at a daily intake of 4.5 kg diet containing 15% CP or 12.5% CP with 0.2% L-lysine addition.

In the final discussion, the implications of recommendations to breeding sows are made for subtropic areas such as Taiwan.

摘要

一、 本論文之研究目的為：(1)測定哺乳母猪的離氨酸需要量，利用其於改善飼料氨基酸的平衡，以降低飼料蛋白質的水準，(2)商業化的母猪飼養环境下測定懷孕母猪的蛋白質與離氨酸需要量，(3)評估玉米飼料添加離氨酸與色氨酸大規模飼養懷孕母猪之效果，(4)探究利用哺乳母猪離氨酸需要量之測定結果應用於降低哺乳母猪飼料蛋白質含量和改善其氨基酸的平衡，大規模飼養母猪之效果。

二、 試驗一，採用36頭外女猪在哺乳期中餵給基本飼料逐級加添離氨酸至0.39，0.49，0.59，0.69和0.79%（%飼料），並且餵給高(1.06%)離氨酸飼料(大麥和大豆粉)。基本飼料添加離氨酸至0.59%改善其氨基酸的平衡，明顯地提高母猪的泌乳量和增加仔猪的增重。哺乳母猪產乳的热能和蛋白質利用效率隨其飼料離氨酸自0.39%提高至0.59%而增高，但飼料離氨酸超过0.59%

則此兩項效率不再增加。哺乳母豬飼餵基本飼料和離氨酸添加飼料者比飼餵高離氨酸飼料者有較高的產乳蛋白質利用效率，但產乳熱能利用效率則反之。在第一胎次中，氮素蓄積和飼料蛋白質的生物價皆隨飼料離氨酸的增加呈Quadratic的提高，其高峯點約於飼料離氨酸0.49～0.59%間。在第一胎次正值氮素平衡發現於母豬攝食0.59%離氨酸飼料組中，第二胎次發現於攝食0.49%以上離氨酸飼料組中。基本飼料中異亮氨酸、離氨酸、蛋氨酸和羥丁氨酸的消化率與其氮素消化率相當。哺乳母豬血漿中的主要氨基酸除去組氨酸和苯丙氨酸皆在餵料後一小時達到最高峯，隨後迅速下降，在餵料後4～16小時間血漿中主要氨基酸達到穩定的含量。哺乳母豬供餵低飼料離氨酸者，其血漿中離氨酸保持低含量，但飼料離氨酸含量至0.59%以上則母豬血漿離氨酸急劇上升；同時飼料離氨酸含量增加，母豬血漿主要氨基酸(離氨酸除外)則為下降，飼料離氨酸增加至0.59%以上時血漿主要

氨基酸則稍反升高。綜合所有的反應，測定哺乳母猪的飼料蛋氨酸需要量為0.58%(含有12.6 MJ DE/kg)，每日需要量第一胎次母猪為31 g，第二胎次以上的母猪為33 g。本研究測定飼料蛋氨酸消化率77%利用於計算可消化蛋氨酸需要量，其結果為0.49%。

三、 試驗二為5×5複因子設計，每區集採用25頭什交女猪，共有8區集，其目的為探究不同蛋白質與添加合成氨基酸之母猪飼料對其生產性能、氮代謝和代謝体液之影响。懷孕母猪供餵下列五种飼料之任何一种：(1) 9%粗蛋白質玉米大豆粉飼料，(2) 如第1項添加0.2%蛋氨酸和0.05%色氨酸，(3) 11%粗蛋白質玉米大豆粉飼料，(4) 13%粗蛋白質玉米大豆粉飼料，(5) 15%粗蛋白質玉米大豆粉飼料。哺乳母猪供餵下列五种飼料之任何一种：(1) 12.5%粗蛋白質玉米大豆粉飼料(基本飼料)，(2) 第1項飼料添加0.2%蛋氨酸，(3) 第2項飼料添加0.05%蛋氨酸，(4) 第3項飼料添加0.025%色氨酸，(5) 15%粗蛋白質玉米大豆粉飼料。

懷孕母猪之增重随其每日蛋白質供餵量之增加呈 Quadratic 的提高，約每日供餵308 g蛋白質時，懷孕母猪之增重達到最高峰。仔猪出生頭数和体重不受飼料处理之影响。懷孕母猪供餵9%粗蛋白質飼料，其每胎离乳仔猪頭数和体重不如其他处理組。懷孕母猪供餵9%粗蛋白質添加离氨酸和色氨酸飼料以及11%粗蛋白质飼料其每胎仔猪离乳頭数和体重如同其他較高蛋白質飼料組的优異成績。在第一胎次中发現懷孕母猪供餵低於13%蛋白質飼料者对其离乳至有效配种間隔有劣影响，不过在第二胎次中並未发現此种劣現象除去9%粗蛋白質添加氨基酸飼料組。

懷孕母猪每日粪尿氮的排泄量随每日蛋白質攝食量的增加而呈綫型的提高。母猪供餵9%粗蛋白質添加氨基酸飼料，其氮素蓄積增加原来未添加氨基酸的47%，这种10.75 g/日氮素蓄積的水準与11%粗蛋白質飼料組相当。雖然氮素蓄積与蛋白質攝食量不呈 Quadratic 的增加，但是懷孕

母猪每日摄食289～315g蛋白质，只增加微少的氮素蓄积。每日氮素蓄积%总氮摄食量为蛋白质利用效率的指标，怀孕母猪摄食9～13%粗蛋白质饲料增加其蛋白质利用效率。

当怀孕母猪供喂9%粗蛋白质添加氨基酸饲料组，其血浆中高氨酸的含量升高，但降低血中尿素含量。当怀孕母猪供喂9～11%粗蛋白质饲料(0.28～0.40%饲料高氨酸)，其血浆高氨酸保持平稳的含量，但供喂饲料粗蛋白质超过11%以上则急剧增高血浆中高氨酸的含量。

基于母猪生产性能、氮素蓄积和血浆尿素与高氨酸含量的反应，怀孕母猪每日供喂2kg饲料，其需要含有11%粗蛋白质与0.44%高氨酸。若9%粗蛋白质饲料添加0.2%高氨酸和0.05%色氨酸亦适合于怀孕母猪的需要。

哺乳母猪饲料处理组对母猪生产性能之影响未达明显的程度。哺乳母猪基本饲料(12.5%粗蛋白质)添加足够高氨酸需要量后，再添加蛋氨酸或合并添加蛋氨酸和色氨酸，并

未能再改善仔豬的增重。

哺乳母豬基本飼料中添加高氨酸後，改善其氮素蓄積和氮素蓄積%總氮攝食量，再添加蛋氨酸或合併添加蛋氨酸和色氨酸則母豬不再增加氮素蓄積和氮素蓄積%總氮攝食量。哺乳母豬供餵基本飼料添加高氨酸，其血漿高氨酸含量明顯增高。基於哺乳母豬的生產性能，氮素代謝和血漿高氨酸等的資料判斷，母豬每日需要32g高氨酸，由每日供餵4.5kg飼料含有15%粗蛋白質或12.5%粗蛋白質添加0.2%高氨酸中獲得。

最後討論中曾應用試驗結果，推薦种母豬的蛋白質與高氨酸需要量作為亞熱帶地區（例如台灣）飼養种母豬的參考。

GENERAL INTRODUCTION

Breeding sows receiving high quality protein in quantities as low as 140 g CP (7% of diet) per day during pregnancy and 620 g CP (12.5% of diet) per day during lactation throughout 3 successive cycles had acceptable productivity (Elsley, MacPherson and MacDonald, 1971). With these low protein intakes, Elsley (1976) has calculated apparently improved gross overall efficiency of protein utilization by sows in comparison with the calculations from sows fed on protein intakes of the Agricultural Research Council recommendations (1967). It suggests that improving amino acid balance in the diet results in reducing dietary protein level for breeding sows. Thus, it seems that all-cereal based diet may serve as the sole source of dietary protein for breeding sows provided adequate amino acid supplementation is ensured.

It is generally acknowledged that lysine is the first limiting amino acid for the lactating sow (Kracht, 1964; Baker, Becker, Jensen, and Harmon, 1970a). The values for lysine requirement of the lactating sow determined by factorial calculation or from feeding experiments vary considerably. Based on the maintenance requirement for non-pregnant gilts and on the quantity of lysine secreted in milk, the lysine requirement of the lactating sow was first estimated at 32.4 g per day (Baker <u>et al</u>, 1970a). This estimate is in general agreement with the findings of several researchers (Salmon-Legagneur and Duee, 1972; Lewis and Speer, 1973; Sohail, Cole and Lewis, 1974; O'Grady and Hanrahan, 1975). But, a value of 20 g per day was reported to satisfy the lysine requirement of the first litter gilt (Boomgaardt, Baker, Jensen and Harmon, 1972).

Though adequate for maintaining litter size and birth weight, maize diet supplemented with lysine is considered to be inadequate for subsequent lactation performance (Hesby, Conrad, Plumlee and Harrington, 1972). A maize diet has been found to be limiting in lysine and tryptophan, for maximum nitrogen retention with pregnant gilts (Allee and Baker, 1970). However, large scale feeding experiments with pregnant sows given lysine and tryptophan supplementations to maize diets have not been reported yet.

A nutritional carry-over from pregnancy to lactation resulted in increased litter gains as gestation protein level increased from 9% to 17% when the sows had been fed on an inadequate low-protein diet (12%) during lactation (Mahan and Mangan, 1975). The maternal tissue reserves gained during pregnancy could be used to provide nutrients during lactation. It would appear to be more efficacious for these sows to be dependent on the lactation diet as the major source of nutrients for milk production.

The purposes of this thesis were a) reviewing the literature on protein and amino acid requirements of breeding sows (Section I), b) evaluating the lysine requirement for the lactating sow (Experiment I), and c) examining the effects of protein levels and amino acid supplementations in diet on nitrogen metabolism, blood plasma metabolite concentrations and the productive performance of breeding sows (Experiment II).

SECTION I: PROTEIN AND AMINO ACID REQUIREMENTS OF BREEDING SOWS

A. METHODS USED IN ASSESSING THE PROTEIN AND AMINO ACID ADEQUACY FOR BREEDING SOWS

1. Sow Productivity

a. Introduction

Groups of sows are fed to a wide range of protein or amino acid intakes throughout 3 or 4 successive pregnancies and/or lactations, and the performance of sow productivity recorded as measured by such parameters as the number of pigs born, birth weight, growth of piglets, milk yield and composition of sows, sow weight changes, and breeding regularity and fertility.

b. Methods of Estimating Milk Yield

Sow milk is the major source of nutrients consumed by the piglet prior to eating adequate creep feed in its early life. It is meaningful that changes in milk yield and composition caused by changing nutrients in the diets, can be accurately measured. Thus, the dietary effects on sow milk yield can be interpreted for the magnitude of growth and development of the young piglet.

The sow does not voluntarily eject milk in response to stimuli other than that provided by the suckling pig. Only immediately after parturition can milk be manually or mechanically expressed from the mammae without the injection of oxytocin. Thus, milk yield by sows is difficult to measure. Braude, Coates, Henry, Kon, Rowland, Thompson and Walker (1947) introduced a technique of intravenous injection of oxytocin into ear vein to induce milk 'let-down' and permit manual removal of the milk. This approach has been used widely in studies of milk composition. This technique has not been used successfully to measure milk yield, because it is poorly correlated with milk yield as estimated by weighing the litter procedures (Salmon-Legagneur, 1965).

Three methods have been developed to measure milk production. The technique of weighing the sow before and after nursing with a difference in weight is least used. The ratio of weight loss to the actual weight of the sow is extremely large. The accuracy of measurement is affected by any slight movement of the sow.

The more commonly used method is to weigh the piglets (litter) before and after suckling. This method is laborious and time consuming but is the best technique currently available for assessing milk production.

The method of weighing the litter before and after suckling is accompanied by many sources of error. Salmon-Legagneur (1970) reported that even with a carefully controlled and accurate test weighing procedure, the deviation between true and estimated milk yield is likely, on average, to differ by 20% and could reach 50% in some cases. Thus, it permits an estimation of the relative milk production of lactating sows within an experiment, but has a limited absolute milk yield. The interval between milkings influences the amount of milk produced. Barber, Braude and Mitchell (1955) compared the results obtained by them and many other workers in this field and found that sows on every hour nursing schedule gave a much greater estimate of milk yield than those on every $2\frac{1}{2}$ or 3 hours. In their experiments, the average interval between successive sucklings was found to be approximately 1 hour. Subsequently, Salmon-Legagneur (1956), Lenkeit and Gütte (1957), Lodge (1959a) and Smith (1959) indicated that more frequent sucklings resulted in higher estimate of milk yield, and suggested a suitable milking interval of 1 to $1\frac{1}{2}$ hours. Duncan and Lodge (1960) reviewed the published data of milking interval and concluded that the milking interval between $1\frac{1}{4}$ and $1\frac{1}{2}$ hours is the range of normal suckling frequency (standard interval), the interval being dependent to some extent on the stage of lactation. Several researchers (Hartman, Ludwick and Wilson, 1962; Mahan, Becker, Norton and Jensen, 1971d) have also supported this evidence.

Daily milk yield is the criterion normally required for lactation performance, but 24-hour recording periods are somewhat laborious and time consuming. In order to avoid these, it is essential that a suitable period is required for extrapolation, to give an accurate estimate of daily milk yield. Berge and Indrebo (1953) studied the duration of milk production by dividing a day into four 6-hour periods. They found that milk yield was slightly lower from 01.00 to 06.00 h, but this variation was small. Mahan et al (1971d) observed that the nursing frequency was reduced between midnight and 04.00 h but the amount of milk yield per nursing was slightly greater, therefore, daily milk yield was more or less the same. A period as long as 12 hours duration has been used by Smith (1959, 1960) and $7\frac{1}{2}$ hours duration by Lodge (1959a) and MacPherson, Elsley and Smart (1969) with reasonable results. Mahan et al (1971d) conducted the studies on the validity of short periods used in evaluating milk production. They concluded that an 8-hour measurement of milk production was considered suitable for estimating 24-hour production although precision was improved by 10% when the measurement was extended to 12 hours or longer. However, the results of Salmon-Legagneur (1965) agree that a period of between 7 and 8 hours duration provides a suitable estimate of milk yield over a 24-hour period. The accuracy of milk yield measures may also be considerably reduced by faecation, urination and insensible losses if sufficient care is not taken. A number of methods have been suggested to overcome or correct faecal and urinary losses including, the use of expanded polystyrene to absorb these excretions (Mahan et al, 1971d), rousing the pigs and making them walk around for a few minutes before the first weighing (Gill and Thompson, 1956), the use of a cold floor to induce faecation and urination (Van Spaendonck and Vanschoubroek, 1964) or adding 10 g for each urination to the net weight of milk consumed while the litter is with the sow (Salmon-Legagneur, 1956). The best way to minimise these losses is by good design of the facilities allowing easy and rapid transfer of the piglets to and from the weighing box and the dam, therefore reducing the time in which these losses can occur.

MacFarlane, Howard and Siebert (1969) proposed a method based on estimating body water turnover of the nursing offspring with tritiated water (HTO) and equating body water turnover to milk intake. Although the HTO method minimised disturbance of the experimental animals, it required that the only source of exogenous water to the nursing offspring was that contained in milk. The HTO method has been applied to sheep (MacFarlane _et al_, 1969), cattle (Yates, MacFarlane and Ellis, 1971), reindeer and caribou (McEwan and Whitehead, 1971), baboons (Buss and Voss, 1971) and rats (Romero, Canas and Baldwin, 1975). Recently, Fowler and McDougall (1972) reported that milk yield of sows could be measured by a deuterium oxide (D_2O) dilution method. This method is the same theory as above. The technique was tested using early weaned pigs which were fed a precisely metered amount of a synthetic milk diet individually in an incubator. The correlation between calculated and actual milk intakes was close ($r = 0.97$). However, the HTO (MacFarlane _et al_, 1969) and D_2O (Fowler and McDougall, 1972) methods may lead to an overestimation of milk intake because these methods equate body water transport of the nursing animal to its milk intake. Body water transport is greater than the water intake by the amount of water produced by oxidation of those milk nutrients not retained in the growth of the tissues of the animal. Holleman, White and Luick (1975) have shown that the HTO/D_2O and Cs methods do not require an estimate of the metabolic water production since milk intake is estimated from the transfer of tracer (HTO or Cs) from the lactating female to the nursing progeny.

Isotope dilution method for measuring milk yield may be of considerable importance in future studies.

2. Nitrogen Balance Techniques

a. Nitrogen Balance

The animal uses the amino acids of the dietary protein mainly to synthesise new tissue, and/or milk protein, and partly for turnover of old tissues, and compensation of endogenous nitrogen losses. Therefore, the amino acid or protein requirements are closely related to protein anabolism, the rate of which can be calculated to a great degree by nitrogen retention using balance techniques. As indicated by Elsley and MacPherson (1972) and Elsley (1976), the aspect of nitrogen balance is attractive in theory but difficult to undertake accurately in practice. It has been reviewed that the values of nitrogen retention may be overestimated due to systematic errors in nitrogen balance experiments (Wallace, 1959; Duncan, 1965). Thus, Hegsted (1963) suggested that a positive nitrogen balance of 0.5 g/day might be compatible with the true equilibrium in man. Mitchell and Edman (1962), and Baker, Becker, Norton, Jensen and Harmon (1966b) suggested that 1 g/day would be closer to the true equilibrium. However, nitrogen balance can relatively allow to compare different protein sources (quality) in isonitrogenous and isocaloric diets, although it has more limited use in studying different intakes of energy and protein between the diets.

b. Urinary Urea and Allantoin

Urinary nitrogen includes various metabolites, namely urea, allantoin, pseudouridine, creatinine and amino acids, deriving directly or indirectly from protein metabolism (Kiriyama, 1970). The amino acids deaminated are those which the body is unable to use due to an excessive protein intake, defective amino acid balance, unavailability of amino acids or combinations of these factors. The ammonia so produced in the detoxification by the liver to urea which is excreted by the kidney (Pfander, 1967). The quantitative excretion of urea can then be measured to indicate the protein or amino acid adequacy for animals. Kiriyama, Suzuki and Iwao (1971) showed that urea excretion was the main variable in total urinary nitrogen output, causing the significant differences in the proportion of nitrogen retained. Growing rats given an arginine deficient diet had an elevated excretion of urea (Prior and Visck, 1973). In experiments with pigs, Brown and Cline (1972, 1974), Easter, Katz and Baker (1974) and Lewis and Speer (1975) demonstrated that total excretion of urea can be used as an indication of amino acid adequacy.

In an attempt to evaluate the dietary protein quality with rats, Kiriyama and Ashida (1964), Kiriyama and Iwao (1969), and Kiriyama (1970) showed that the ratio of urinary allantoin to urea multiplied by protein intake ($IA/U \times I_p \times 100$) varies directly to the dietary amino acid balance. This index was found to be more sensitive than the biological value.

3. Factorial Approach

The principles of this method are based on the measurement, in absolute terms, of the specific protein or amino acid requirements for a various physiological functions. These can be summed into a total requirement for the animal. This is similar to the classical method employed by Blaxter and Mitchell (1948) with cattle.

The factorial method has been used by many workers (Mitchell, Carroll, Hamilton and Hunt, 1931; Moustgaard, 1962; Lodge and Lucas, 1959; Vanschoubroek and Van Spaendonck, 1966, 1973; Baker et al, 1970a; Whittemore and Elsley, 1976).

The information required for this type of calculation is indicated by Elsley and MacPherson (1972) as follows:

a. Protein or amino acid requirements, needed for maintenance, dependent upon the losses of endogenous urine nitrogen, metabolic faecal nitrogen, and cutaneous nitrogen.

b. Amount of protein and amino acids ingested and their availability, i.e. digestibility coefficients and the biological value of dietary protein used.

c. Protein deposition in the uterus, and mammary gland, in the maternal tissue and the production of milk protein.

d. The influence of the environment, in terms of temperature and of stress, on the efficiency with which protein is utilised.

e. The nutritional status of the animal in relation to the dietary protein status in the previous and subsequent reproductive cycle.

The factorial approach, at the present time, has several important limitations. Firstly, the basal data listed above have not been determined within any single experiment, or a series of experiments. Secondly, the factorial approach is based on absolute figures used in calculation. Many of the data are difficult to measure in absolute terms as they are not subject to complete random experimental error. Therefore, the basal data used in factorial calculation must be carefully selected.

4. Blood Metabolites

a. Concept of the Use of Blood Metabolites

i. Plasma Free Amino Acid

Amino Acid Requirement

When increasing amounts of the limiting amino acid are added to a diet in which this amino acid is low, the concentration in plasma of this amino acid remains low as long as it is inadequate to meet the requirement, and then sharply increases as soon as requirement is satisfied for maximum growth. The determination of the inflexion point of the curve makes possible the evaluation of requirement for amino acids.

Many researchers have used the plasma free amino acid criterion to estimate amino-acid requirements for various species: Stockland, Meade and Milliere (1970) with rats; Zimmerman and Scott (1963), Fonseca, Rogler, Featherston and Cline (1970), and D'Mello (1974) with the chick; Mitchell, Becker, Jensen, Harmon and Norton (1968b), Pick and Meade (1970), Bravo, Meade, Stockland and Nordstrom (1970), Keith, Christensen and Owen (1972), Oestemer, Hanson and Meade (1973), Lewis and Speer (1973, 1974a,b., 1975), and Woerman and Speer (1976) with pigs; Young, Hussein, Murray and Scrimshaw (1971), Young, Tontisirin, Ozalp, Lakshmanan and Scrimshaw (1972), Tontisirin, Young, Miller and Scrimshaw (1973), and Tontisirin, Young, Rand and Scrimshaw (1974) with the human; Patureau-Mirand, Prugnaud and Pion (1973a,b) with the pre-ruminant calf; Patureau-Mirand, Theriez and Prugnaud (1975) with the pre-ruminant lamb. On the other hand, McLaughlan and Illman (1967) investigated that the amino acid requirements for rats were measured by addition of graded levels of the limiting amino acid to the diet until the plasma level of this amino acid was equivalent to that characteristic of a fasting animal that had been maintained with an optimal diet.

Availability

Levels of free amino acids in the plasma could be excellent response criteria for predicting the availability of amino acids from different proteins. A suitable reference diet contains neither excess nor inadequate amounts of amino acids and supports maximal performance of the test animal to establish baseline levels for each of the amino acids in the plasma (Smith, 1966). Also, all amino acids must be fully available from the reference diet. Using the plasma amino acid method, Smith and Scott (1965a,b) and Hill and Olsen (1967) with chicks, and Combs, Connes, Berry and Wallace (1967) with pigs, have shown that over-heating protein feedstuffs had deleterious effects on the availability of some amino acids, mainly lysine. Stockland, Meade and Nordstrom (1970a), Stockland and Meade (1970) found that some amino acids such as isoleucine and threonine were not fully available for the rat and pig from different sources of meat and bone meals. Larbier, Guillaume and Calet (1971), Pion and Pawlak (1973) reported that drying and storage of cereal grains had adverse effects on the availability of lysine and methionine measured by plasma and muscle amino acid levels.

Amino Acid Deficiency and Excess

The procedure developed by Longenecker and Hause (1959) has served as a base for numerous studies in the dog, pig, rat and man related with the assessing of the limiting amino acid in a protein, They measured a plasma amino acid ratio as follows:

$$\text{Plasma Amino Acid Ratio (PAAR)} = \frac{\text{Plasma concentration after feeding} - \text{Fasting plasma concentration}}{\text{Amino Acid Requirement}} \times 100$$

The plasma concentration represented the average of five measurements taken at hourly intervals after feeding the test protein. The fasting plasma concentration represented the measurements of blood taken 16 hours after fasting. As a result of the increases observed in plasma lysine and threonine in chicks during fasting, Hill and Olsen (1963) suggested the concentrations of plasma amino acids after feeding a protein-free diet in place of the fasting values as proposed by Longenecker and Hause (1959). McLaughlan and Morrison (1968) have reviewed the results of studies using this procedure for the determination of limiting amino acids in proteins. These researchers concluded that this approach was limited to the detection of the first, second and non-limiting amino acids.

In the studies of amino acid deficiencies or excess in dietary protein for chicks, Dean and Scott (1966) were able to determine the sequence of limiting amino acids, using the concentration of essential amino acid in plasma after feeding the test diet minus the concentration after feeding the reference diet divided by the reference diet values multiplied by 100. The precision of this approach depends upon supplying the exact requirement for each amino acid in the reference diet (Smith, 1966; Stockland et al, 1970a).

ii. Plasma Urea

Urea is the end product of nitrogen metabolism in terrestrial vertebrates (Hahler and Cordes, 1966), therefore the underlying assumption is that the amino acids deaminated are those which the body is unable to use due to an excessive protein intake, defective amino acid ratios, unavailability of amino acids or combinations of these factors. The ammonia so formed is detoxified by the liver to urea which is transported in blood vessels to the kidney and excreted therein (Pfander, 1967). The blood plasma concentration of urea can then be measured to indicate protein catabolism.

Kumta and Harper (1961), in their studies with rats, demonstrated that an amino acid imbalance raises the blood urea content, and this content could be reduced by correcting the amino acid balance. In pigs, plasma urea values were found to have a negative correlation to weight gain and feed utilisation when proteins from various sources were included in the diet (Puchal, Hays, Speer and Jones, 1962). An improvement in overall utilisation of dietary protein may be reflected by lower levels of blood urea, several workers (Münchow and Bergner, 1968; Bravo et al, 1970; Eggum, 1970, 1973, 1976; Brown and Cline, 1974; Lewis and Speer, 1973, 1974a,b, 1975; Tontisirin et al, 1973; Braude, Fulford, Mitchell, Myres and Porter, 1974) have shown that measurement of blood urea levels can offer an alternative and simpler method of assessing requirements both for dietary protein and/or amino acids.

iii. Miscellaneous

Other blood components which include total serum protein and serum electrophoretic protein fractionations (namely albumin, α-globulin, β-globulin, and γ-globulin) have been investigated to evaluate protein adequacy for sows. Results have indicated that these criteria are not sensitive enough to assess protein adequacy (Rippel, Harmon, Jensen, Norton and Becker, 1965b; Pond, Strachan, Sinha, Walker, Dunn and Barnes, 1969; Hesby, Conrad, Plumlee and Harrington, 1970b; Eggum, 1976).

b. Factors Affecting Concentrations of Free Amino Acid and Urea in Blood Plasma

i. Introduction

The concentration of amino acids in plasma at any one time depends upon various factors. This input depends partly on the diet, thus varying according to the amount of amino acids ingested and to their availability, and partly on tissue protein catabolism where the amino acids are released into the blood stream, depending on the period of fast. The output depends on the rate of anabolism for the syntheses of new tissues and/or milk protein, and for turnover of old tissues, together with amino acid degradation for the excretion of surplus amino acids. If plasma free amino acid is used to assess the accurate adequacy of dietary protein for animals, it appears, therefore, to know some factors affecting levels of free amino acid in blood plasma.

Three factors, at least, influence blood urea content, the quality and quantity of protein in the diet and the time of blood sampling after feeding (Eggum, 1973). Thus, to use blood urea measurement as a sensitive technique for assessing protein adequacy, it is necessary to know the factors affecting levels of blood urea.

ii. Factors Affecting Concentration of Free Amino Acid in Blood Plasma

Time of Blood Sampling after Feeding or Fasting

Maximum levels of essential amino acids are generally obtained one to two hours after feeding (Nordstrom, Windels, Typpo, Meade and Stockland, 1970; Pick and Meade, 1970; Typpo, Meade, Nordstrom and Stockland, 1970; Windels, Meade, Nordstrom and Stockland, 1971; Davey, Phelps and Thomas, 1973), the decline to baseline levels occuring some two to ten hours later (Nordstrom et al, 1970; Pick and Meade, 1970; Typpo et al, 1970; Windels et al, 1971).

Boomgaardt and McDonald (1969) studied fasting plasma amino acid patterns in piglets weighing about eight kg. They concluded that the concentration of amino acids in plasma becomes almost uniform between twelve and twenty hours after feeding, and that this period may be chosen as a reference value. Richardson, Hale and Ritchey (1965) reported that the amino acids were considerably lower in blood plasma from growing pigs fasted for twelve hours than they were in those fasted for twenty-four hours, but none of the differences was significant. Subsequently, a number of workers (McLaughlan and Illman, 1967; Harker, Allen and Clark, 1968; Typpo et al, 1970; Nordstrom et al, 1970; Pick and Meade, 1970; Windels et al, 1971) have demonstrated that the period from four to sixteen hours after feeding represents a suitable length of time for blood sampling from rats and growing pigs for assessing protein adequacy.

There is little published data about the effect of length of blood sampling time after feeding on plasma free amino acid levels in sows. In studies with pregnant sows, blood samples were withdrawn one hour after the once daily feed by several researchers (Lucas, Holden, Speer and Hays, 1969; Holden, Ewan and Speer, 1971; Woerman and Speer, 1976). Holden et al (1971) and Woerman and Speer (1976) took blood samples after 23 and 24 hours of fasting. In studies with lactating sows, Lucas et al (1969) chose at three hours after the morning feed to collect blood samples but Lewis and Speer (1973) chose at five hours. According to data from Ganguli, Speer and Zimmerman (1971), the plasma free amino acid concentrations of lactating sows did not differ significantly between two sampling hours (at one and five hours after the morning feed), except for lysine. A lower concentration of lysine was recorded at a five-hour sample. Lewis and Speer (1974b) reported that postprandial plasma free amino acid levels of lactating sows (about two hours after feeding) were more sensitive response to amino acid intake than were fasting levels (sixteen hours after feeding).

Metabolic Adaptation

McLaughlan and Illman (1967) with rat, Zimmerman and Scott (1967) with chicks, Mitchell et al (1968b) and Stockland et al (1970a) with pigs showed that a period of metabolic adaptation was necessary before plasma free amino acid levels could accurately be used to measure the amino acid requirement. Pick and Meade (1970) reported that the results after one or nine feedings (4.5 days) are different from each other, and different from the findings of Mitchell et al (1968b) and Pion, Prugnaud, Henry and Rerat (1972) obtained after twelve days. Knipfel, Keith, Christensen and Owen (1972) subsequently showed that a period of four days allowed metabolic adaptation to take place in growing pigs.

Feeding Pattern

Stockland et al (1970) showed the effect of feeding methods on the shape of the plasma-free amino-acid response curve. If rats were fed at a one-hour period every twelve hours for seventeen days, the lysine requirement by measuring PAA concentration gave similar results to those obtained using ADG and G/F. If rats were fed ad libitum and blood was taken six hours after the feed was removed, the lysine requirement, based on plasma free lysine, gave lower results than those obtained using ADG and G/F as criteria. There is no way of controlling the time at which the rat last feeds in the above procedure and, therefore, the length of the fast period to collection of blood samples probably varied. It appears that a period of 'metabolic adaptation' to different feeding method is necessary. Stockland et al (1970) investigated that the test diets were fed to growing pigs both at one-hour period (1/4 of a day feed) with blood collected six hours after feeding and hourly (1/24 of a daily feed) for six hours with blood collected one hour after last meal. The latter procedure was performed in an effort to make the amino acids removal from plasma closely approximate to the absorption from the gastrointestinal tract. They found feeding test diets hourly over a six-hour period instead of a one-hour period had no effect on plasma free amino patterns. Bravo et al (1970) also achieved the same results.

Site of Sampling

Variations of the amino acid concentration presented in peripheral blood are less than those found in the portal blood, owing in particular to the retention of amino acids by the liver (Ostrowski, 1969; Nordstrom et al, 1970; Typpo et al, 1970; Bloxam, 1972) for protein synthesis or for catabolic purposes. In experiments with growing pigs, Pion and Rerat (1976) found the ratio of portal to jugular free amino acids in blood samples taken after feeding the balanced diet were not very high, except at one hour after feeding when they reached to about 1.5. These ratios are always lower in the blood taken after feeding the lysine deficient diet; it is clear that the amino acid concentration tended to remain higher in the jugular blood than in portal blood three to five hours after feeding. However, studies to define more accurately the effect of protein or amino acid concentration in a diet on the plasma amino acid levels are generally taken on peripheral blood (Rerat, 1972).

Dietary Protein Level

Changes in concentration of free amino acids in the plasma response to dietary protein levels, particularly as far as lysine and threonine are concerned, have been demonstrated by several researchers (Richardson, Cannon and Webb, 1965; Harker et al, 1968; Pawlak and Pion, 1968; Pick and Meade, 1970). Some less accurate information may be inferred from plasma amino acid levels of animals fed dietary proteins of various amino acid compositions (Patureau-Mirand. Toullec, Paruelle, Prugnaud and Pion, 1974).

Physiological Stage of Animals

Holden et al (1971) reported that the plasma lysine and threonine of pregnant sows decreased as gestation progressed, although this phenomenon was not apparent to Woerman and Speer (1976). In the work of Duee and Rerat (1975), pregnant sows fed a diet containing 0.43% lysine had significant higher values of plasma free lysine and essential amino acids (excluding lysine) on day 60 of pregnancy than on day 90 of pregnancy. They resulted in different lysine requirements for gestation sows, using lysine level in the blood taken on days 60 and 90 of pregnancy, Consequently, Duee (1976) concluded that physiological stage of animal, particularly as far as pregnancy advanced, is an important factor affecting the plasma amino-acid levels.

3. Factors Affecting Concentration of Urea in Blood Plasma

Quantity of Dietary Protein

In experiments with rats, Eggum (1970) showed that there is a positive correlation ($r = 0.95$) between the protein content in a diet and the blood urea content in the same feeding rat. The similar responses of blood urea to dietary protein content were demonstrated by Anderson and Edney with dogs (1969), Münchow and Bergner (1968) with rats, Davey et al (1973) with pigs, and Fonnesbeck and Symons (1969) with horses.

Quality of Dietary Protein

Many workers (Kumta and Harper, 1961; Bravo et al, 1970; Brown and Cline, 1974; Lewis and Speer, 1973, 1974a,b, 1975; Braude et al, 1974; Orok and Bowland, 1975; Woerman and Speer, 1976) have shown that experimental animals fed imbalanced amino acid diets had elevated concentrations of blood urea. Eggum (1970), Münchow and Bergner (1968), and Bergner, Münchow and Reischuck (1971) also found a high negative correlation between the biological value of the dietary protein and blood urea. Bergner et al (1971) also concluded that, under strictly standardized conditions, measurement of blood urea levels could be used to estimate the protein quality of practical rations for growing pigs.

Length of Time after Feeding

In the instance of growing pigs, the urea concentration in the blood plasma reached maximum levels three hours after feeding (Eggum, 1970; Davey et al, 1973). These findings are in agreement with the results of Anderson and Edney's experiment (1969) with dogs. It suggests that the most suitable time to take blood samples in a standardized trial was 4-5 hours after feeding.

Although these factors tend to mask the unique amino acid pattern of ingested protein, the balance of evidence is that with well planned and executed experiments, evaluation of amino acid or protein adequacy can be achieved by the plasma free amino acid method. It appears that measurements of amino acid or protein adequacy for growing pigs under practical conditions require at least a duration of four to five days, with feed given in separate meals and the taking of blood samples from peripheral vein four to eight hours after feeding. However, optimum sampling times in breeding sows have not been studied systematically.

By standardizing conditions such as dietary protein, feed and water intake, time of sampling blood after a meal, and duration of feeding test meal, thus, protein quality would become the decisive factor affecting blood urea levels and thus blood urea becomes an alternative criterion of protein adequacy.

B. REVIEW OF THE LITERATURE ON PROTEIN REQUIREMENTS OF PREGNANT SOWS

1. By Sow Productivity

a. Sow Weight Changes

The results from numerous experiments (Boaz, 1962; Clawson, Richards, Matrone and Barrick, 1963; Salmon-Legagneur, 1963; Rippel, Rasmussen, Jensen, Norton and Becker, 1965a; Pond, Wagner, Dunn and Walker, 1968a; Pike and Boaz, 1969; Baker, Becker, Jensen and Harmon, 1970b,c; Frape, Wilkinson, Chubb and Wolf, 1971; Hawton and Meade, 1971; Hesby, Conrad, Plumlee and Martin, 1970a; O'Grady, 1971; D'Geeter, Hays, Kratzer and Cromwell, 1972; Greenhalgh, Elsley, Grubb, Lightfood, Saul, Smith, Walker, Williams and Yeo, 1974; Mahan and Mangan, 1975) show that sow weight gain increased as protein intake increased during pregnancy.

Maximum net gestation gains by sows are generally achieved by a daily intake of 300 g CP (Holden, Lucas, Speer and Hays, 1968; Baker et al, 1970b; Elsley, 1973).

b. Number of Pigs Born and Birth Weight of Pigs

Several workers (Rippel et al, 1965a; Pond et al, 1968a, 1969; DeGeeter et al, 1972) have shown that gilts given extremely low protein intakes (9-55 g) were not significantly affected in terms of number or weight of pigs born. Diets containing cereals as the sole source of protein fed to pregnant sows have been found to be adequate for producing normal litter size and birth weight (Boaz, 1962; Baker et al, 1970b,c; Hesby et al, 1970a, 1972; Frape et al, 1971; Hawton and Meade, 1971). It is clear that the amount of protein in the gestation diet, expressed either in g consumed or a percent of the diet, is not an important factor in affecting litter size or birth weight.

c. Milk Yield

The results of Elsley and MacPherson (1964, 1966), Stothers and Milne (1964), Salmon-Legagneur (1965) and Neilsen (1968) demonstrated that the protein intake of sows during pregnancy has a minimal effect on the milk production in early lactation. Elsley and MacPherson (1972) found that effect of protein intake during pregnancy on the milk yield in the subsequent lactation was not apparent by seven days postpartum. Thus, it is not worthwhile feeding high level of protein during pregnancy for enhanced milk yield in the subsequent lactation period.

d. Growth of Pigs

Preweaning

Although pregnant sows have a remarkable capacity to provide nutrients for developing fetuses during periods of severe protein restriction, it should be noticed that a stunting effect on the progeny may be induced by severe and prolonged protein restriction of the dam during pregnancy.

Using reciprocal transfer nursing method, Pond et al (1968a) demonstrated that severe protein deprivation of the dam from day 24 of pregnancy to parturition significantly depressed gains of piglets due to reduce sow's milk yield, but not due to prenatal nutrition. This result is supported by the findings of DeGeeter et al (1972), who fed pregnant gilts at a daily intake of 45 g CP. Subsequently Pond et al (1969) also observed that weaning weight gain was also significantly depressed in progenies of protein-deprived gilts throughout gestation compared with that of protein-adequate gilts.

Clawson et al (1963), Holden et al (1968) and Elsley et al (1971, 1973), demonstrated that pregnant sows receiving the high quality protein in quantities as low as 140 g per day had acceptable growth of piglets. Maize diets fed alone (Baker et al, 1970b,c; Hesby et al, 1970a; Hawton and Meade, 1971) or supplemented with L-lysine (Hesby et al, 1972), though adequate for maintaining litter size and birth weight, were considered to be inadequate for subsequent lactation performance. However, Frobish, Speer and Hays (1966), and Greenhalgh _et al_ (1974) shows that the pregnant sow fed 180 g CP per day from mixed diets had satisfactory growth rate of piglets. Other researchers have demonstrated that pregnant sows fed over a wide range of daily protein intake (200-530 g CP) were not different in growth of their progenies (Boaz, 1962; Nielsen, 1968; Pike and Boaz, 1969; Pike, 1970; Frape _et al_, 1971; O'Grady, 1971; Baker, Molitoris, Jensen and Harmon, 1974).

Postweaning to Slaughter

Pond, Dunn, Wellington, Stouffer and Van Vleck (1968b) reported that gilts given a protein-free diet from day 24 of pregnancy to parturition did not affect the postweaning growth rate of their progenies. More recently, DeGeeter, Hays, Kratzer and Cromwell (1973) also found that pregnant sows fed at 45 g CP per day during gestation did not significantly affect the postweaning performance of their offspring, although a trend toward slower gains of piglets from dams fed the low protein diet did exist.

However, Pond _et al_ (1969) reported that the progeny of gilts deprived of protein throughout pregnancy had significantly smaller daily gains from weaning to slaughter than the progeny of gilts given a 16% protein diet (control diet). Reduction in DNA (an estimate of cell number) in tissues of rats and pigs malnourished during early postnatal life (Winick and Noble, 1966, 1967; Dickerson, Dobbing and McCance, 1967) has been demonstrated and the ratio of RNA to DNA in the tissues has been taken as an index of protein synthetic activity. In the results of Pond _et al_ (1969), no difference in DNA content of brain or skeletal muscle were observed between progenies of gilts fed the control diet and those of gilts fed the protein-free diet throughout pregnancy, but RNA content of the cerebrum and RNA/DNA ratio of the longissimus muscle was greater in pigs from control sows at slaughters (90 kg). These differences were interpreted as indicating reduced protein synthetic activity of the cerebrum and longissimus muscle in progeny of protein-deprived gilts (Pond, 1973).

Livingstone, MacPherson, Elsley, Lucas and Lodge (1966) reported that the offspring from sows given diets containing 10% protein during gestation had the same growth rate and feed conversion as the offspring of sows fed diets containing 18% CP during pregnancy. These results are also supported by the work of Baker _et al_ (1970c), Hawton and Meade, (1971), who compared the development of offspring from sows given all maize diet with those from sows fed maize-soybean diets (13.7-18.8% CP).

e. Composition and Carcass Characteristics of Pigs at Birth and at Slaughter

Elsley, McDonald and MacPherson (1966c) found that the chemical composition of new born pigs from sows given as little as 180 g CP per day throughout gestation was similar to those from sows given 500 g CP per day. These results are also supported by the findings of Hesby _et al_ (1970a) and Elsley _et al_ (1973).

Pond _et al_ (1968b) reported that carcass characteristics (back-fat thickness, carcass length and loin-eye area) of pigs at slaughter were not significantly affected by gestation treatment of dams fed a protein-free diet or a 16% CP diet.

Livingstone (1962) showed that new born pigs from pregnant sows fed 21.2% CP diet had a significantly greater thickness of muscle fibres in muscle dorsi and muscle psoas majoris than those from sows fed 10.4% CP diet, although these effects in pigs disappeared at market weight. Subsequently, Livingstone _et al_ (1966) showed that pregnant sows fed 10 or 18% CP diets had no apparent effect on carcass characteristics of their progenies at slaughter. This finding is also agreed by the work of Hawton and Meade (1971).

f. Breeding Regularity and Fertility

During pregnancy extremely low daily protein intake (36 g CP) has been found to adversely affect breeding regularity (Svajgr, Hays, Cromwell and Dutt (1970)). Holden et al (1968) reported that pregnant sows fed the high quality protein as low as 140 g per day for 4 successive reproductive cycles had no indication of any adverse effects on breeding regularity. However, Hawton and Meade (1971) indicated that gilts fed all maize diet throughout pregnancy had an indication of adverse effect on subsequent conception and ability to maintain pregnancy.

Greenhalgh et al (1974) showed that a wide range of dietary protein levels (9-15% CP) fed to the pregnant sows for 4 successive reproductive cycles has not been found to adversely affect breeding regularity.

Baker et al (1974) examined pregnant sows fed all maize diet until day 80 of pregnancy then 16% protein diet prior to parturition (average of 206 g CP per day). They found that these weaned sows returned to service normally.

Boaz (1962) observed that pregnant sows fed all cereal diets providing 280 g crude protein daily would slightly increase the average intervals between weaning and effective re-service as compared with those fed high quality and quantity of protein during pregnancy. Subsequently, Pike and Boaz (1969) reported that breeding regularity of sows fed all cereal protein diet providing 284 g CP per day during pregnancy was normal as compared with those fed fish meal diet providing 526 g CP per day. Nielsen (1968) fed pregnant sows at average of 318, 398 and 477 g CP daily and found that breeding regularity was without adverse effect from treatments.

In summary it can therefore be stated that based on published optimal performance of sows productivity, the pregnant sow requires about 200 g CP per day.

2. By Nitrogen Balance

a. Some Factors Affecting Nitrogen Balance of Pregnant Sows

i. Quality of Dietary Protein

In the experiments undertaken by Rippel, Harmon, Jensen, Norton and Becker (1965c), and Allee and Baker (1970) with pregnant gilts, maize fortified with lysine and tryptophan considerably improved the nitrogen retention. Nearly 3 to 4 g per day increase in nitrogen retention resulted. These results are supported by the work of Hesby et al (1970b), who found that nitrogen retention was much higher in pregnant sows given opaque-2 maize than those given all maize diet which has deficiencies of lysine and tryptophan. Therefore, nitrogen retention of pregnant sows is dependent on the quality of the dietary protein fed. Easter et al (1974) fed pregnant gilts with amino acid mixture to levels of essential amino acids recommended by the National Research Council (1973). The nitrogen retention achieved was 13.63 g per day and this is considered to be more than adequate for optimal reproductive performance.

ii. Stage of Pregnancy

Although Evans (1929) and Mitchell et al (1931) observed no consistent tendency for nitrogen retention, that nitrogen retention of pregnant sows increases with pregnancy advanced has been shown by Gütte and Lenkeit (1960). Positive nitrogen balance resulted throughout pregnancy at a daily intake of 193 g CP but it did not increase in nitrogen retention when pregnancy progressed. Nitrogen retention increased only after the 70th day of gestation as increasing daily intake of protein up to 662 g CP. Elsley and MacPherson (1964) also showed nitrogen retention increased in late pregnancy with gilts given 468 g crude protein daily, but not with those given 287 or 176 g. Subsequently, Elsley, Anderson, McDonald, MacPherson and Smart (1966a) fed pregnant gilts at 308 g CP daily and resulted in that nitrogen retention tended to increase linearly with pregnancy progress. This evidence is supported by the work of Salmon-Legagneur and Rerat (1962), Rippel et al (1965b), Pike (1970), Kline, Anderson and Melampy (1972) and Kaczmarczyk (1973).

Elsley and MacPherson (1972) have indicated that an increase in nitrogen retention as pregnancy progressed is important because it may compensate for the increased need of protein deposition in the uterus and mammary gland in late pregnancy. If the ability of pregnant sows to increase dietary protein utilization is sufficient, an increase in protein intake in late gestation may not be necessary.

According to evidence, nitrogen retention increased as pregnancy advanced, two possibilities could be postulated: (a) protein or amino acid requirements during the first two-thirds of gestation are very much lower than during the final one-third of gestation, and (b) a low protein diet fed during the first two-thirds of gestation depleted the sow to an extent where nitrogen retention for repletion was more efficient in the last one-third of gestation when a higher protein diet was fed.

iii. Energy Intake during Gestation

Elsley and MacPherson (1964) fed gilts either 1.6 or 2.6 kg/day of isocaloric diets containing either 10.5 or 18.0% CP throughout pregnancy, the protein qualities being similar for both diets, to determine the effect of daily intakes of feed and protein on nitrogen retention of pregnant gilts. The studies were conducted throughout three successive cycles. The results showed that nitrogen retention was related to both the total intake of dietary protein and energy. An increase in daily feed intake of 1.6 to 2.6 kg led to an increase in nitrogen retention, although the daily protein intake was similar for both treatments. It appears that the increasing nitrogen retention in late pregnancy can only be obtained when the intake of energy is sufficient. If energy is limiting, it is inevitable that a proportion of the dietary protein will be used as source of energy rather than of protein. This finding is also supported by the study of Elsley, Anderson and MacPherson (1966b) and Pike (1970), who fed pregnant sows at different daily feed intakes of protein and energy.

iv. Pregnancy Anabolism

That the efficiency of protein utilisation by pregnant gilts is higher than by non-pregnant gilts has been shown by several researchers. The studies of Rippel et al (1965b), and Baker et al (1966b) indicated that the biological value of 3% protein maize-soybean meal diet was 99% for gravid gilts and 69% for the non-gravid gilts. In the experiment of Elsley et al (1966a), the nitrogen retention of gravid gilts was greater than for non-gravid gilts. The difference in nitrogen retention between gravid and non-gravid gilts was almost entirely accountable to increase protein deposition in the products of conception, and in the uterus and the mammary gland by the gravid gilt. This finding is in agreement with the results of Kline et al (1972). Thus, the evaluation of protein requirement for pregnancy based on the data from non-gravid animal must be an overestimate (Salmon-Legagneur, 1965; Elsley et al, 1966a; Heap and Lodge, 1967).

b. Requirements

Nearly all the studies have indicated that nitrogen retention increases as daily intake of protein increased (Gütte and Lenkeit, 1960; Elsley and MacPherson, 1964; Elsley et al, 1966b; Rippel, et al, 1965b; Miller, Becker, Jensen, Harmon and Norton, 1969; Hesby et al, 1970b; Pike, 1970; Jones and Maxwell, 1974). The results of

Rippel et al (1965b) showed that sows given 25.5 MJ (6.0 Mcal) ME/day during late gestation required 3.0% CP of a diet for maintenance but for maximal nitrogen retention levels of up to 12.5% CP (230 g CP/day) of a diet were required. Miller et al (1969) found that a 15% CP (285 g per day) diet was required to maximise nitrogen retention. Elsley (1973, 1976) has indicated that the gilts mated at 105-120 kg live weight do not normally reach mature weight until the third or fourth parity. Thus, pregnant gilts tend to increase protein intake, in an attempt to achieve mature size. The protein requirement for the pregnant sow measured by maximal nitrogen retention inevitably leads to require higher protein allowance. If nitrogen needs for the products of conception, for uterine and mammary growth are estimated at 3.5 g per day (Moustgaard, 1962; Elsley et al, 1966a; Elsley, 1967), nitrogen needs for cutaneous losses are estimated at 1 g per day (Baker et al, 1966b; Elsley and MacPherson, 1972) and nitrogen needs for maternal growth are estimated at 4.2 and 6.3 g per day which is based on 20 and 30 kg maternal live gains for the normal and optimal performance of sow productivity (Vanschoubroek and Van Spaendonck, 1973; Whittemore and Elsley, 1976), this adds up to about 9 and 11 g of nitrogen retention needed daily during gestation.

3. By Factorial Approach

Based on the factorial approach, Moustgaard (1962) estimated that the average protein requirement for pregnancy was 350 g CP per day, and the actual requirement rose from 312 g CP for the first 90 days of pregnancy to 470 g CP daily for the last 10 days of pregnancy. Based on the metabolism data of Mitchell et al (1931), Lodge and Lucas (1959) estimated that the protein requirement of a 182 kg live weight sow carrying 12 pigs was 276 g CP per day over the whole pregnancy. Moustgaard's estimate was high because he allowed 235 g CP daily for the growth and maintenance of the sow. Using the factorial calculation, Vanschoubroek (1963) estimated that 12% CP diet would be adequate for pregnant sows. Recently, Vanschoubroek and Van Spaendonck (1973), and Whittemore and Elsley (1976) estimate that the average protein requirement for pregnant sows is 210 g CP per day, by taking new attitudes to the growth of maternal tissue and carefully selecting basal calculation data.

4. By Blood Metabolites

Lucas et al (1969) examined the adequacy of dietary protein for breeding sows fed 8, 12, 16 and 20% CP with uniform protein quality throughout 4 successive pregnancies. The results did not demonstrate the protein adequacy for gestation sows. It might be considered that the low control diet (8% CP) containing 0.43% lysine was adequate for pregnancy. Thus, the plasma free lysine of pregnant sows could not result in quadratic trend. However, they suggested that 8% CP diet at a daily intake of 140 g CP would be adequate in all essential amino acids with exception of sulphur amino acids for pregnant sows.

C. REVIEW OF THE LITERATURE ON AMINO ACID REQUIREMENTS OF PREGNANT SOWS

1. Arginine

In vivo synthesis of arginine in a quantity adequate to meet maintenance requirements has been demonstrated conclusively in man (Rose, Haines and Warner, 1954), rats (Burroughs, Burroughs and Mitchell, 1940) and pigs (Baker _et al_, 1966a). However, both the young growing pig and the rat require a dietary source of arginine for maximal growth. Rippel _et al_ (1965d) suggested that the arginine requirement for pregnant sows was no greater, but probably less, than the 0.38% (6.8 g daily) contained in the casein based diet. More recently, Easter _et al_ (1974, 1976) clearly showed that postpubertal female pigs, whether gravid or non-gravid, can synthesise adequate arginine to meet their needs for postpubertal growth and fetal development, based on nitrogen balance and reproductive performance criteria.

2. Histidine

Using nitrogen balance method, Rippel _et al_ (1965d) suggested that the histidine requirement of pregnant gilts was no greater, probably less, than 0.17% (3.1 g daily) of the casein based diet. Subsequently, based on nitrogen retention and plasma urea criteria, Easter _et al_ (1974) demonstrated that 0.13% histidine (2.6 g per day) of the diet was adequate for the pregnant gilt.

3. Isoleucine

Based on short-term nitrogen balance criterion, Rippel _et al_ (1965c) concluded that the pregnant gilt required 0.37% isoleucine (6.7 g daily) of the diet during late pregnancy.

4. Leucine

Rippel _et al_ (1965d) suggested that the pregnant gilt required no more than 0.56% (10.2 g per day) dietary leucine. Subsequently, based on nitrogen balance, blood urea and hemoglobin criteria, Easter et al (1974) found that a daily intake of 6.4 g leucine (0.32%) diet was adequate for pregnant sows.

5. Lysine

Rippel et al (1965c) demonstrated that the pregnant gilt needs 0.42% (7.6 g per day) lysine contained in the diet to achieve maximal nitrogen retention. Salmon-Legagneur and Duee (1972), and Duee and Rerat (1974) found no more than 0.44 and 0.43% dietary lysine (8.8 and 8.6 g per day), respectively, were required for pregnant sows, measured by the blood urea criterion. Subsequently, Duee and Rerat (1975) carried out an experiment on lysine requirement of pregnant sows. The results show that the addition of lysine to the basal diet up to 0.43% during pregnancy improves sow weight gain, birth weight of piglets, number of piglets weaned, weaned weight of piglet, and nitrogen retention. Although more lysine supplementation to the basal diet up to 0.63% results in higher nitrogen retention and concentration of plasma free lysine, they have concluded that the pregnant sow requires no less than 0.43% (8.6 g per day) of dietary lysine. More recently, results of Woerman and Speer (1976) confirmed their findings. Woerman and Speer (1976) reported that urinary nitrogen excretion decreased and nitrogen retention increased as dietary lysine increased. Beyond 0.41% dietary lysine, the urinary excretion decrease and the nitrogen retention increase were minimal. Similarly, plasma urea decreased and plasma lysine increased as dietary lysine levels increased with inflections in the response curves beyond the 0.30% lysine level. Milk yield, milk solids and nitrogen were near maximum in those sows fed 0.41% lysine. Pig gains were near maximum at 0.30% lysine level. However, it should be noted that three sows given 0.30% dietary lysine or less had been found to adversely affect breeding regularity. Considering all the parameters, a level of 0.43% lysine (7.8 g per day) meets the lysine requirement of pregnant sows.

6. Phenylalanine

Rippel et al (1965d) suggested that the pregnant gilt required no more than 0.30% (5.4 g per day) dietary phenylalanine when the diet contains 0.33% tyrosine. Jensen (1975) suggested that a value of 0.33% dietary phenylalanine was required for pregnant sows.

Rose and Wixom (1955) reported that tyrosine was capable of exerting a sparing effect of 70 to 75% upon the phenylalanine requirement of man. However, Baker et al (1966b) found that tyrosine had very little replacement value for maintenance requirement of phenylalanine. Jensen (1975) suggested that tyrosine could satisfy 30% of the phenylalanine requirement of pigs.

7. Sulphur Amino Acids

Rippel et al (1965c) estimated the sulphur amino acid requirement of pregnant gilts by nitrogen retention during late pregnancy. Their results suggested that the sulphur amino acid requirement was 0.29% (5.2 g per day) of the diet. Based on reproductive performance, nitrogen retention and plasma free amino acid criteria, Holden et al (1971) demonstrated that the pregnant gilt required 0.18% (3.3 g per day) dietary sulphur amino acids.

Methionine alone can satisfy all the sulphur amino acid requirement of the animal because it is readily converted into cystine in the body. Rose and Wixom (1955) observed that 75% of the methionine requirement of the adult rat could be provided by cystine, whereas only about 16% could be in the diet of the growing rat. In the young pig, Becker, Jensen, Terrill and Norton (1955) have suggested that cystine can satisfy 40% of the total sulphur amino acid need for optimal growth, which is somewhat lower than the values of 50, 53 and 70% reported by Shelton, Stein and Moore (1951), Curtin, Loosli, Abraham, Williams and Maynard (1952), and Mitchell et al (1968a), respectively.

However, Baker et al (1966c) demonstrated that cystine could supply 94% of maintenance need for sulphur amino acids. The explanation for this apparent difference may be that a great part of maintenance requirement of amino acids is for keratin synthesis, whereas keratin synthesis is a minor factor in the requirement for growth. In gravid gilts, cystine can be used to supply no more than 32% of the sulphur amino acid need (Rippel et al, 1965c).

8. Threonine

Based on nitrogen balance, Rippel et al (1965d) found that the pregnant gilt required 0.34% (6.2 g per day) dietary threonine. More recently, nitrogen retention and plasma free amino acid data from sows during late pregnancy led Duee (1976) to conclude that 0.36% dietary threonine (7.2 g per day) satisfied the pregnancy requirement.

9. Tryptophan

Rippel et al (1965d) showed that the tryptophan requirement of the pregnant gilt was no greater than 0.07% (1.3 g per day) of the casein based diet.

10. Valine

Rippel et al (1965d) showed that the valine requirement for the pregnant gilt was 0.46% (8.4 g per day) of the casein based diet.

These published amino acid requirements for the pregnant sow are summarised as follows:

Amino Acid	Rippel et al (1965c, d) (% of diet)	Recent Published Results (% of diet)
Arginine	0.38*	not necessary (Easter et al, 1974, 1976)
Histidine	0.17*	0.13 (Easter et al, 1974)
Isoleucine	0.37	-
Leucine	0.56*	0.32 (Easter et al, 1974)
Lysine	0.42	0.44 (Salmon-Legagneur and Duee, 1972)
		0.43 (Duee and Rerat, 1974)
		0.43 (Duee and Rerat, 1975)
		0.43 (Woerman and Speer, 1976)
Phenylalanine	0.30*	-
Sulphur Amino Acids	0.28	0.18 (Holden et al, 1971)
Threonine	0.34	0.36 (Duee, 1976)
Tryptophan	0.07*	-
Valine	0.46	-

* Probably in excess of the requirement.

D. REVIEW OF THE LITERATURE ON PROTEIN REQUIREMENTS OF LACTATING SOWS.

1. By Sow Productivity

a. Milk Production and Composition

i. Factors Affecting Milk Yield

A thorough review of non-nutritional factors affecting milk yield by the sow has been published by Elsley (1970), and Whittemore and Elsley (1976).

Litter Size

As the litter size increases the total milk production of the sow will also increase, but the milk production per piglet will decrease correspondingly (Elsley, 1967, 1970; Whittemore and Elsley, 1976).

Parity

Elsley (1970) has shown that the milk yield varies according to lactating number. This evidence is also observed by Vanschoubroek and Van Spaendonck (1966), who measured the mean milk yield of sows over five successive parities. They have concluded that the milk yield increases from the first lactation to a maximum in the second or third and decreases gradually thereafter until the sixth lactation. The differences were greater for milk yield than for milk composition. The fat content of the milk tends to decline in the third lactation and this may be associated with declining fat reserves of sows (Whittemore and Elsley, 1976). However, Salmon-Legagneur (1965) found no clear differences in milk yield existed between the second and fifth lactations.

Stage of Lactation

The normal lactation curve has a general trend to peak around the second to fourth week postpartum and to remain at a fairly high level until the fifth or sixth week, then to decrease rapidly (Perrin, 1954a; Barber et al 1955; Gill and Thomson, 1956; Lodge, 1959a; Smith, 1959; Elsley, 1970; Whittemore and Elsley, 1976).

ii. Effect of Protein Intake on Milk Yield and Composition

Lodge (1959b) fed diets containing 11, 15 and 19% CP in amounts sufficient to maintain constant body weight of lactating sows and found that milk yield and the amount of protein output in the milk were not affected by dietary protein levels. Salmon-Legagneur (1964) found no significant effects on the yield or on the concentrations of the major milk constituents, when 14 or 19% dietary protein was fed, except for lactalbumin and urea, in which case both constituents were higher with the 19% protein diet. Nielsen (1968) fed diets containing 16% and 13% dietary protein, and indicated that milk yield and composition had no significant differences between treatments. MacPherson et al (1969) fed lactating sows at three levels of dietary protein (19, 16.5 and 14% CP) with lysine contents of 0.97, 0.79 and 0.61% respectively, and found no significant differences between treatments for milk yield and compositions. Only over successive lactations a significant decrease in fat production occurred in the third lactation with this low protein diet.

Elsley et al (1971 and 1973) fed sows at three levels of dietary protein (7, 10 and 13%) during pregnancy and at two levels of dietary protein (12,5 and 16%) in lactation. The results showed that increasing the level of dietary protein in lactation increased milk production, but the increases were small. From the co-ordinated sow experiments of Greenhalgh et al (1972, 1974), diets containing 9, 11, 13 and 15% CP were fed during pregnancy, and 9, 13 and 17% CP in lactation for four successive cycles. They found that milk yield, the quantitative production of dry matter in milk and protein content of milk decreased significantly with decreasing protein levels of the lactation diets in the third lactation.

Mahan, Becker, Harmon and Jensen (1971c) fed lactating sows low (10%), medium (14%) and high 18%) protein and opaque-2 maize (9.7% crude protein) to evaluate the dietary effects on milk yield and composition. They found that milk yield was reduced by reducing the protein level from 18% or 14% to 10%, but there was no difference in milk yield between sows fed 14% and 18% CP diets. Albumin appeared to be the most sensitive criterion for evaluating protein adequacy since it was the only fraction of milk that was reduced as protein level was reduced. They also reported that the quantitative production of milk components was reduced as dietary protein levels were reduced. The lower production values were mainly caused by depressing the milk yield. The influence of dietary protein (5, 10 and 15%) during last 30 days of gestation and throughout lactation on the composition of colostrum and subsequent milk was measured (Elliott, Vander Noot, Gilbreath and Fisher, 1971). The protein content of colostrum was slightly greater from sows fed the 15% CP diet. Concentration of protein, amino acids, dry matter, fat, lactose, ash, vitamins (A, C, thiamin and riboflavin) and cholesterol did not vary due to treatment. Lenkeit and Gütte (1957) also reported a decrease in milk yield from 10.7 to 3.6 kg/day as digestible protein intakes were reduced from 736 to 246 g per day. Work, Henke and Harris (1942) indicated that 10% CP in the lactation diet led to reduced milk yield as compared to the 14% CP diet.

b. Growth of Piglets

MacPherson et al (1969) reported that lactating sows given diets containing 14, 16.5 and 19% CP on a daily base 5.3 kg had no difference among treatments in piglet growth. They suggested sows did not require more than a 14% protein diet with a lysine content of 0.61% or 750 g crude protein per day during lactation.

Elsley et al (1971, 1973) fed sows at three levels of dietary protein (7, 10 and 13%) during pregnancy and at two levels of dietary protein (12.5 and 16%) in lactation. They found that increasing the protein level in the diet during lactation increased piglet growth, but the increase was small. This evidence is also supported by the results of Nielsen (1968).

Greenhalgh et al (1974) fed diets containing 9, 11, 13 or 15% CP during pregnancy and 13 or 17% in lactation. They indicated that the progenies of sows given more protein in lactation grew faster, although the differences were not consistently significant.

Results by O'Grady (1971) showed that as little as 11.7% CP diet fed to lactating sows ad libitum did not reduce piglet growth as compared to the 16% CP diet.

The protein requirement with maize-soybean meal diets for lactation has been reported by Mahan, Becker and Jensen (1971a). By varying the ratio of maize and soybean, protein levels of 10, 12, 14, 16 and 18% on an average daily basis 3.5 and 4.1 kg of feed were fed to the 1st and 2nd litter sows during lactation. In addition, opaque-2 maize (9.7% protein) was fed with non-protein supplementation. Average piglet growth at 28 day weaning was maximised at 16% protein (656 g CP per day). First-litter sows fed opaque-2 maize supported similar litter gains to those from sows on 14% CP. However, second-litter sows performed similarly to those on 10% CP.

Work et al (1942) showed that piglets from lactating sows fed a 10% CP diet gained less to 8 weeks than those from sows fed a 14% CP diet. Greenhalgh (1972) indicated that litters from sows given the 9% CP throughout grew normally in parity 1, but reduced growth in parities 2 and 3 as compared with those from sows fed 13 and 17% CP diets. Holden et al (1968) fed diets containing 8, 12, 16 and 20% CP throughout four successive pregnancies and lactations. Equal protein quality was maintained in all diets by diluting a 20% CP diet with equal part of cornsugar and cornstach. The pregnant sows were given 1.82 kg of feed while lactating sows were fed to appetite twice per day. The results showed that an improvement in pig gain was noted as the protein level was increased to 16% but the difference was not significant. It should be noted that the 8% CP diet used in their experiment was of a higher protein quality than all-cereal diets.

Elliot et al (1971) fed diets containing 5, 10 and 15% CP to gilts during last 30 days of gestation and throughout lactation. The pregnant gilts received 2.0 kg of feed and lactating sows were fed twice daily at a total of 4.5 kg of feed. They reported that litter gain from sows fed the 5% CP diet were significantly less than that from sows fed the other two diets. This evidence is also supported by the results of DeGeeter et al (1972), who fed diets containing 5 or 17% protein to the lactating sow.

c. Sow Weight Change

Elsley and MacPherson (1966) reported that some maternal weight loss of sows during lactation appeared to be usual phenomenon even though sows received protein intakes almost identical to those recommended by the ARC (1967). Elsley (1972) has suggested that sows gaining between 12 and 15 kg from cycle to cycle (mating to weaning) at least during the first four parities would be a reasonable overall index of nutritional adequacy for sows. In practical conditions, it allows sows to have some reasonable weight loss during lactation.

Holden et al (1968) fed 8, 12, 16 and 20% protein of maize-soybean meal diets with equal protein quality throughout four successive pregnancies and lactations. They found no significant difference among treatments in weight loss of sows weaned at 2 weeks after farrowing. Sows fed low protein diets ate more during lactation, evidently in an attempt to meet the increased requirements of lactation, or possibly as a result of their decreased gestation gain.

DeGeeter et al (1972) showed that lactating sows given the 5% CP diet lost more weight than those given the 17% protein diets (41.3 vs 11.0 kg) during the 4-week lactation period. They also found that the most pronounced weight losses were observed during the third and fourth week of the lactation. Elliot et al (1971) indicated average weight losses of sows given the 5, 10 and 15% CP diets represented 26, 23 and 20% of their post-farrowing weights with the greatest losses for sows fed the 5% CP diet.

Mahan et al (1971a) found that weight losses of both first and second litter sows during lactation were influenced by the dietary protein level. The lower the protein level in the diet, the greater the weight loss. A quadratic decrease in lactation weight losses occurred as dietary protein increased with a marked weight loss occurring in those sows given either a 10% or opaque-2 maize diet. These results confirm the findings of Work et al (1942).

MacPherson et al (1969) found that first lactating sows given the low protein diet (14% CP) had a significantly greater weight loss in 42 days of lactation than the other two treatments (16.5 and 19% CP), but these differences were not significant in the second and third lactation. O'Grady (1971) reported that sows receiving low protein intakes (11.7% CP) had a greater weight loss during lactation in three parities compared with higher protein intake (16% CP). Nielsen (1968) also reported that sows given the 13% CP diet had a greater weight loss than those given the 16% CP diet.

Greenhalgh (1972) reported sows fed the 13% CP diet in lactation lost more weight than those fed the 17% CP diet. Subsequently, Greenhalgh et al (1974) showed sows receiving the 13% CP diet in lactation caused a greater weight loss then, but a greater gain in the following pregnancy. At the end of the fourth lactation the difference between treatment-means for sow weight was only 12 kg.

d. Breeding Regularity and Fertility

Lodge (1972) has suggested that sow weight loss during lactation exceeds the gain of the preceding pregnancy for several reproductive cycles, with possible adverse effects on fertility. The effect of protein intake of lactating sows on breeding regularity and fertility has received little attention until recently.

According to MacPherson et al (1969), there was no indication that the diets containing 14, 16.5 and 19% CP fed to the lactating sow had any effect on breeding regularity. Most recently, this evidence is also agreed by the findings of Greenhalgh et al (1974).

Holden et al (1968) reported that sows given a range of protein levels (8 to 20% CP) had not been found to adversely affect the conception rate, and oestrus cycle length of sows. It should be noted that the 8% CP diet used in their experiment was a higher protein quality than all-cereal diet and that lactating sows were fed to appetite and weaned at 2 weeks after farrowing. Thus, sows receiving 8% protein diet had about 12 kg of net weight gain from cycle to cycle.

Elsley et al (1968, 1969) fed the sow at low feed intake which allowed the sow to return to approximately its initial weight by the end of each lactation, over three reproductive cycles, with no apparent effects on the fertility of the dam. Lodge (1959a) suggested that there appeared to be a delay in recommencing the oestrus cycle in sows fed on low planes of nutrition but there was insufficient evidence to confirm this. The lack of evidence that the receiving of the low protein (less than 10% CP) diet over several reproductive cycles has any adverse effect on the fertility of the sow still exists. The decreasing interval between weaning and effective service is associated with reduction in maintenance costs of the sow, and with increasing the number of piglets produced per year markedly. It needs to be received much more attention in future studies.

Based on published data of milk yield, litter gain, sow weight loss and breeding regularity, it is generally considered that the lactating sow requires between 14 and 16% CP of the diet. In terms of daily intake this represents between 700 and 750 g CP.

2. By Nitrogen Balance

a. Utilisation of Protein by Lactating Sows

The lactating sow has two sources of protein available for synthesising milk protein. These are digested protein from the food and labile or reserve protein in the animals when in negative nitrogen balance.

Protein utilisation by lactating sows has been described in detail by Gütte and Lenkeit (1960), Elsley (1970, 1976) and Elsley and MacPherson (1972). They have indicated that the nitrogen retained by sows varies considerably during the course of lactation. Immediately following parturition sows excrete a much higher content of nitrogen in the urine, reaching its peak between 3 and 5 days postpartum. This high excretion of urinary nitrogen is closely related to high nitrogen retention in pregnancy. As a result of this loss, the sow is frequently in negative nitrogen balance during the early stages of lactation, even if the daily protein intake is high and despite the fact that production of milk and milk protein has not yet reached its maximum. This phenomenon makes it difficult to measure the adequacy of dietary protein during the first 10 days of the lactation period.

Gütte and Lenkeit (1957) presented the coefficient (k) of digested protein utilisation for milk production and maintenance in the form of an equation:

$$K = \frac{\text{Milk N} + \text{E.U.N.} + \text{M.F.N.} + \text{Deposited N}}{\text{Digested N} + \text{Mobilised Body N}}$$

Milk N = Nitrogen in milk

E.U.N. = Endogenous urine nitrogen.

M.F.N. = Metabolic nitrogen in faeces.

Deposited N = Body retention of nitrogen when the animal is in positive nitrogen balance.

Digested N = Digested nitrogen.

Mobilised Body N = Catabolism of body protein nitrogen when the animal is in negative nitrogen balance.

Gütte and Lenkeit (1957) found that the efficiency of digested protein utilisation for milk production and maintenance by lactating sows over a wide range of protein intakes was varied from 60 to 70%, with a mean of 65%. This figure is confirmed by the work of MacPherson and Elsley (1970) with a value of 68%. A 65% efficiency of utilising digestible protein for milk production and maintenance has been suggested for use in formulating lactation diets (Gütte and Lenkeit, 1957), but this figure is of little value as a guide to the optimal protein level in the diet as sows are in negative nitrogen balance during all, or a great part of lactation.

The gross efficiency of conversion of dietary protein into milk protein and allowing for maintenance or growth by a sow receiving adequate energy and little excess protein was calculated to be approximately 33% by both Lodge (1959b) and Gütte and Lenkeit (1957). In the experiment of MacPherson and Elsley (1970), they found that the gross efficiency of converting dietary crude protein into milk protein varied between 30 and 45%. More recently, O'Grady, Elsley, MacPherson and McDonald (1973) examined the effects of dietary energy intake during lactation upon yield and composition of sow's milk and also growth rate of litters throughout three successive cycles. That the lactating sow receiving in excess of 750 g CP per day had a mean of 37% efficiency of converting dietary protein into milk protein was also supported. That 33% efficiency coefficient has been used by the ARC (1967), calculating the protein requirements for lactating sows, may be too low.

Based on both apparent digestibility of the protein and nitrogen retention as % total N intake, utilisation of protein by the lactating sow is better than by the pregnant sow. Salmon-Legagneur (1965) found apparent digestibility of the protein during lactation was as high as 86% compared with a figure of only 79% during pregnancy. Apparent digestibility of the protein in excess of 80% has been consistently found by Lodge (1959b), Elsley and MacPherson (1966), and MacPherson *et al* (1969). In the experiment of Woerman and Speer (1976) with breeding sows, the pregnant gilts receiving the diet ensured lysine adequacy resulted in 33-37% of N retention as % of total N intake, whilst the lactating sow retained nitrogen at 52-54% of the total nitrogen intake.

b. Effect of Protein Intake on Nitrogen Balance

Lodge (1959b) investigated the influence of protein intake upon milk production and nitrogen balance in lactating sows, given diets containing 11, 15 and 19% CP with a feeding scale to maintain each sow at constant weight. He found that the sow receiving 15% CP in the diet was in positive nitrogen balance and that receiving 11% CP was in negative balance. The major effect of increasing protein intake of lactating sows was an increase in the output of urinary nitrogen. In the studies of Elsley and MacPherson (1966), and MacPherson and Elsley (1970), the lactating sow received 760-775 g CP and 68 MJ (15.8 Mcal) DE per day would allow slight positive nitrogen balance and the production of adequate milk. Using maize-soybean meal diets, Mahan et al (1971b) demonstrated that an average of 720 g CP (16% CP, 4.5 kg/head/day) was adequate for maintenance of nitrogen equilibrium in the lactating gilt associated with low energy intakes during 4 weeks of lactation period. However, Ganguli et al (1971) reported that lactating sows fed 420 g high quality crude protein daily were in positive nitrogen balance, but this response was associated with lower milk yield. Lewis and Speer (1973) fed all-maize diets supplemented with essential amino acids to levels similar to those suggested by Baker et al (1970a) for the lactating sow at a daily protein intake of 580 g. The results showed that those sows were in positive nitrogen balance. The intakes of essential amino acids in Lewis and Speer's (1973) experiment were also comparable with the study of MacPherson and Elsley (1970). It can, therefore, be postulated that cereal based diets or a daily intake of 600 g CP is satisfactory for lactation performance provided adequate amino acids supplementation is ensured. It is apparent that the measurement of protein requirement for lactating sows which support zero nitrogen balance during lactation is very much dependent upon the quality of dietary protein, on the milk yield and on the intake of energy.

3. By Factorial Approach

The ARC (1967) has used the factorial approach to estimate the protein requirements of lactating sows. They calculated protein allowance using data on estimated milk yield, milk protein content, a 33% gross efficiency of converting dietary protein into milk protein, and allowing for maintenance and slight growth. These calculations indicated that the average daily protein requirement for a sow suckling 8 piglets for an 8-week period would be in excess of 1000 g CP. When fed in conjunction with the ARC (1967) energy recommendations (78.4 MJ DE for sow weighing 180 kg and suckling 8 piglets) the diet should contain 16.1% CP on air-dry basis, to meet the recommended protein requirements. Based on metabolism data, Gütte and Lenkeit (1960), gave a value of 969 g CP per day for a 200 kg live weight sow suckling 8 piglets. Using factorial approach, Vanschoubroek and Van Spaendonck (1966) indicated that a diet should contain 18-19% CP for lactating sows. More recently, Whittemore and Elsley (1976) estimates that the lactating sow requires 938 g CP per day.

The recommendation of protein allowance for the lactating sow by these workers is in close agreement.

4. By Blood Metabolites

Lucas et al (1969) measured the plasma amino acid profiles for lactating sows which were given 8, 12, 16 and 20% protein of maize-soybean meal diets with equal protein quality. The results did not demonstrate the protein adequacy for lactating sows. However, they suggested that the 8% CP diet of a high quality nature, when given to lactating sows at 456 g CP per day, was considered adequate in all essential amino acids except for sulphur amino acids. It might be that their lactating sows fed diets to appetite varied in feed intake. Thus, the concentrations of free amino acids in lactating sows varied. Therefore, the quadratic response of plasma free amino acids of the lactating sow could not be detected.

The estimate of protein requirements for lactating sows, based on factorial approach, is higher than those based on either sow productivity or on nitrogen balance. It is considered that a diet containing between 14 and 16% CP or in terms of daily intake 750 g CP from natural feedstuffs is adequate for lactating sows. If amino acid supplementations in the lactation diet are ensured, the protein requirement for lactating sows would be reduced to 600 g CP (12.0% CP) or less (Elsley, 1970).

E. REVIEW OF THE LITERATURE ON AMINO ACID REQUIREMENTS OF LACTATING SOWS

1. Isoleucine

Ramamurthy and Stothers (1975) estimated the isoleucine requirement of lactating sows based on lactation performance, nitrogen balance, plasma isoleucine and urea criteria. Pig weight gains, milk yield and composition increased linearly with maxima at 0.50-0.65% dietary isoleucine level. Nitrogen balance and plasma isoleucine were low for sows received 0.35% isoleucine. Plasma urea level decreased as the dietary isoleucine level increased. They concluded that a lactating sow with 9 piglets, consuming 4.5 kg feed daily containing 10% CP, required a minimum of 0.50% (22.5 g per day) isoleucine. However, Haught and Speer (1976) reported that the isoleucine requirement of lactating sows was 0.28-0.37% (15.3-20.2 g per day) of the diet. Milk yield and pig weight gains increased quadratically as dietary isoleucine increased. Response curves of nitrogen retention, plasma isoleucine and urea levels of lactating sows had inflection points at 0.28-0.37% dietary isoleucine.

2. Lysine

The values for lysine requirement of the lactating sow measured by factorial calculation or from feeding experiments vary considerably. Baker et al (1970a) first estimated that the lysine requirement of the lactating sow, based on the maintenance requirement (Baker et al, 1966a, b, c; Baker and Allee, 1970) for a non-pregnant gilt and on the quantity of lysine secreted in milk, was 32.4 g per day. Their estimate is in agreement with the calculation vaule of Speer (1974). Boomgaardt et al (1972) added graded levels of lysine to a basal diet containing 0.60% lysine in order to measure the lysine requirement of lactating sows. No significant differences in any of the lactation performance were observed, and they concluded that the lysine need of the first-litter lactating sow does not exceed 0.60% (20 g per day) of the diet. Based on biological efficiency of converting dietary protein into milk protein when there was no net change in the body pool of nitrogen, McDougall and Fowler (1974) suggested that the lysine requirement of the lactating sow did not exceed 26.4 g (0.43% of diet) per day. Salmon-Legagneur and Duee (1972) found that the lactating sow required 37.3 g lysine per day (0.69% of diet), based on blood urea criterion. Their finding is in close agreement with the results of Sohail et al (1974), who used concentrations of plasma free amino acids and blood urea as criteria.

Lewis and Speer (1973) determined the lysine requirement for lactating sows, based on lactation performance, nitrogen balance, and plasma amino acid and urea as criteria. Nitrogen retention, pig weight gain, milk total solids and milk protein increased quadratically with increasing levels of lysine with maxima at 0.48 to 0.66% lysine. Milk yield increased quadratically with a maximum at 0.48% lysine. Plasma lysine was low in sows fed diets containing less than 0.48% lysine, but increased quadratically above this level. Plasma essential amino acids (excluded lysine and tryptophan) and urea levels decreased linearly with increasing dietary lysine. They concluded that a sow consuming 5.45 kg per day of diet required a minimum of 0.55% (30 g per day) lysine for optimal lactation performance. More recently, O'Grady and Hanrahan (1975) demonstrated that the lactating sow requires 0.58% (26 g per day for the first lactation and 33 g per day for later lactations) of the diet to achieve maximum litter performance. It appeared that the interval between weaning and mating was longer following low-lysine diets (0.43% of diet) fed in the first lactation. But such effects did not appear after later lactations.

3. Sulphur Amino Acids

Estimating the sulphur amino acid requirement for lactating sows was conducted by Ganguli et al (1971). Nitrogen retention, net nitrogen balance, milk yield and milk protein content were lack of response to methionine supplementations. However, 2-week pig gain was maximised at 0.23% sulphur amino acids. Plasma cystine increased linearly and plasma methionine increased quadratically as dietary methionine increased. The response curve of plasma methionine had a sharp inflection point at 0.36% sulphur amino acids. They concluded that 0.23 to 0.36% total dietary sulphur amino acids satisfied the requirement of the lactating sow fed 5.45 kg feed per day. More recently, O'Grady and Hanrahan (1975) indicated that the sulphur amino acid requirement of the lactating sow is no greater than 0.39% (17.6 g per day for the first lactation and 21.8 g per day for later lactations) of the diet.

In young pigs the cystine can supply 70% of the sulphur amino acid requirement (Mitchell et al, 1968a), in gravid gilts not more than 32% (Rippel et al, 1965c). However, Baker et al (1966c) demonstrated that the cystine could supply 94% of maintenance need for sulphur amino acids. The sparing effects of cystine on total sulphur amino acid requirement of lactating sows have not been studied.

4. Threonine

The threonine requirement of the lactating sow was estimated on the basis of lactation performance, nitrogen retention, plasma essential amino acid and urea levels, and urea excretion (Lewis and Speer, 1975). Milk yield increased quadratically with increasing levels of threonine, reaching a maximum at 0.49% threonine. Pig gains also were maximal at this threonine intake. Nitrogen retention and milk protein increased as threonine level increased from 0.31 to 0.42%, Plasma threonine increased quadratically as dietary threonine increased, remaining at a low level until 0.42% threonine, and increasing sharply at higher dietary threonine levels. The plasma essential amino acids decreased with increasing dietary threonine, reaching a plateau at 0.42% threonine. Plasma urea concentrations and urine urea excretions decreased rapidly as dietary threonine level increased from 0.31 to 0.42%. The results indicates that a sow consuming 5.45 kg of feed per day requires a minimum of 0.42% (22.9 g per day) threonine for optimal lactation performance.

5. Tryptophan

The tryptophan requirement of the lactating sow was measured on the basis of nitrogen retention, plasma essential amino acids and urea, and lactation performance (Lewis and Speer, 1974a). Nitrogen retention, milk yield and milk protein increased quadratically with increasing levels of tryptophan, reaching a plateau by 0.09% tryptophan. Pig gain increased linearly as tryptophan level increased. Plasma tryptophan increased in a sigmoid manner as dietary tryptophan increased, with an inflection point at about 0.091% tryptophan. Plasma urea decreased as dietary tryptophan increased. They concluded that the lactating sow required 0.072% (3.9 g per day) tryptophan of the diet supplying 62 g nitrogen per day. When no essential amino acids were limiting, 100 g of nitrogen intake per day was adequate to support optimal lactation performance and maintain nitrogen equilibrium (Lewis and Speer, 1973). Assuming the tryptophan requirement as a percent of protein nitrogen remains constant, then dietary tryptophan requirement was calculated as 0.12% (6.3 g per day) at the level of 100 g nitrogen intake.

The published amino acid requirements of lactating sows are summarised in Table 1.

Table 1: AMINO ACID REQUIREMENTS OF LACTATING SOWS (g per day)

Amino Acid	Baker et al (1970a) *	Speer (1974)**	Recent Experimental Results
Arginine	13.6	22.5	-
Histidine	10.4	12.7	-
Isoleucine	26.8	19.0	22.5 (Ramamurthy & Stothers, 1975) 15.3-20.2 (Haught & Speer, 1976)
Leucine	39.6	37.2	-
Lysine	32.4	33.2	20.0 (Boomgaardt et al, 1972) 37.3 (Salmon-Legagneur & Duee, 1972) 30.0 (Lewis & Speer, 1973) 26.4 (McDougall & Fowler, 1974) 38.4 (Sohail et al, 1974) 33.0 (O'Grady & Hanrahan, 1975)
Methionine & Cystine	14.4	15.8	16.4 (Ganguli et al, 1971) 21.8 (O'Grady & Hanrahan, 1975)
Phenylalanine & Tyrosine	40.0	38.0	-
Threonine	20.4	20.0	22.9 (Lewis & Speer, 1975)
Tyrptophan	5.2	5.8	6.3 (Lewis & Speer, 1974a)
Valine	27.2	23.2	-

* Based on maintenance, 6 kg daily milk yield (5.2% protein), 4 kg daily feed intake, 80% availability of amino acid.

** Based on 7.25 kg daily milk production (4.83% protein), 5.45 kg daily feed intake, and 82.5% availability of amino acids.

SECTION II: EXPERIMENTAL PROCEDURES

A. DIETS AND TREATMENTS

1. Experiment I

Experimental dams all received the same diet based on barley and wheatings during pregnancy and after weaning (Appendix 1). This could be designated as 'low' protein diet on the basis of the ARC (1967). During lactation the sows received one of 6 experimental diets (Appendix 1): the basal diet containing 0.39% lysine, four diets which were formulated from the basal diet supplemented with one of 4 graded levels (0.1, 0.2, 0.3 and 0.4%) of lysine, the sixth diet based on barley and soybean meal served as a high lysine (1.06%) control diet.

2. Experiment II

The composition of the gestation and lactation diets are shown in Appendixes 3 and 4, respectively. A basal diet (L.B.) containing 12.5% crude protein and 0.54% lysine was designed to be the low-control lactation diet. A high protein control diet (H.C.) containing 15% crude protein and 0.76% lysine was designed similar to the dietary protein level for lactation recommended by MacPherson et al (1969) and the NRC (1973).

B. ANIMALS AND THEIR MANAGEMENT

1. Experiment I

Thirty-six closely related gilts weighing about 90 kg were selected on the basis of backfat thickness measured ultrasonically. The gilts were individually fed 2.6 kg of a diet containing 15% crude protein until mating at the first heat following 126 kg live weight. All dams were mated twice during a 24 hour period and each was given 2.0 kg of the 'low' protein diet once a day throughout pregnancy. On day 110 of gestation the dams were transferred to farrowing crates. At first farrowing dams were randomly allocated to one of the six dietary treatments according to their order of farrowing. In the second parity, sows were returned to the same treatment to which they were allocated as gilts. Litter size was standardized to 9 within 3 days postpartum in the first parity, and to 10 thereafter. The dams were fed the 'low' protein diet according to litter size until 2 days postpartum. Experimental diets were fed to sows beginning on day 3 postpartum. First and second litter sows were given 5.3 and 5.7 kg, respectively, of feed per head daily during lactation in two equal meals. The feed was given with about $1\frac{1}{2}$ times of its weight of water, and unlimited additional water was provided. All piglets received injection of 200 mg Fe and male pigs were castrated at 3 days of age. Creep feed (Appendix 1) was offered from 7 to 42 days of age. Weaning took place at 42 days after farrowing and 2.0 kg feed per day of the low protein gestation diet was fed to the sow again.

2. Experiment II

Eight separate blocks of 25 crossbred gilts of mixed breeding and weighing approximately 116 kg at breeding were used. Each gilt was mated by artificial insemination on two separate occasions at an interval of at least 12 hours. The gilts, within each block, were allocated at random to one of the five gestation treatment groups (diets) during pregnancy. They were confined in sow stalls and individually fed 2 kg diet once daily. Gilts were placed in farrowing crates on the 110 day of pregnancy. Within each block, sows farrowing from each of the five gestation treatment groups (diets) were randomly allotted to one of the five lactation treatment groups (diets) according to their farrowing sequence. Litter size was equalized to 8 and 9 pigs respectively, within 3 days after birth for the first and second lactation. Sows were fed the lactation diets from the second meal of the first day postpartum to weaning; they were given 4.0 kg feed daily in two equal meals during the first lactation period and 4.5 kg feed daily during the second lactation period. All piglets were given an injection of

200 mg Fe after birth. Male piglets were castrated at 14 days of age, and creep feed (Appendix 5) was offered *ad libitum* between day 10 to 28 of age. All litters were weaned at 4 weeks of age. After weaning, the sows were returned to the sow stalls, fed 2 kg of the 13% CP gestation diet once a day until mated, and then returned to the same treatment regime allocated before during two further successive parities. The results contained in this thesis only relate to the first two lactations.

C. MEASUREMENTS

1. Experiment I

Dams were weighed on the day of first mating and on day 110 of pregnancy. The piglets and dams were weighed at birth and weekly postpartum, and in addition the piglets were also weighed at 4 days of age. Feed intakes of sows and litter were recorded daily throughout.

2. Experiment II

The dams were weighed immediately on the day of service, on the 110th day of pregnancy, immediately after parturition, and on the 28th day of lactation. The piglets were weighed at birth and at days 4, 10 and 28 of age. Feed consumption of sows and litters were recorded daily throughout.

D. MILK RECORDING AND SAMPLING

1. Experiment I

Estimates of milk yield for 4 sows in each of the six treatments were obtained by weighing litters before and after suckling at 1 hour intervals for an 8-hour period weekly for parity 1, and on days 14 and 28 of lactation for parity 2. Prior to obtaining milk samples, the litter was separated from the sow for about 1 hour. Milk samples were obtained from the same sows for chemical analyses using an intravenous injection of 5 IU oxytocin followed by manual expression of the milk samples. Milk samples were stored at $-15^{\circ}C$ prior to analysis.

2. Experiment II

Milk samples for chemical analyses were obtained from 7 sows in each of the five lactation treatment groups at 21 days postpartum. The method of sampling milk was similar to that described above.

E. NITROGEN METABOLISM

1. Experiment I

a. Nitrogen Balance of Pregnant Sows

After an adaptation period of 3 days in the metabolism cages, 6 pregnant sows were subjected to 5-day nitrogen balance collections. The collection periods were from day 88 to 93 and 100 to 105 of pregnancy for the first parity, and day 45 to 55, 88 to 93 and 100 to 105 of pregnancy for the second parity. Faeces were collected in a plastic container with dilute H_2SO_4 added daily. Urinary collection was accomplished via a Foley catheter (size 24), attached to a length of Tygon tubing and urine drained into a 40-litre bottle containing dilute H_2SO_4.

b. Nitrogen Balance of Lactating Sows

After an adaptation period of 3 days in the metabolism cages, two sows of each treatment were subjected to two successive 5-day nitrogen balance trials between day 17 to 22 and 23 to 28 postpartum, respectively. The method of collecting faeces and urine were similar to that described above. The milk yield and milk nitrogen value used for each nitrogen balance was the average value obtained before and after each balance trial.

c. Digestibility of Essential Amino Acids by Sows

Six sows (parity 2) on day 35 postcoitum were employed in a lysine digestibility trial. Each sow was fed 2.0 kg of the low lysine basal diet (Appendix 1) each morning at 09.30 h throughout the experimental period. After a 10-day adaptation period, each sow was subjected to two 5-day collection periods. The first and second periods were conducted 45 to 50 and 50 to 55 days postcoitum respectively. Faecal and urinary collections were conducted as described above. Apparent digestibility of essential amino acids in the low lysine basal diet was determined.

2. Experiment II

a. Nitrogen Balance of Pregnant Gilts

Nitrogen balance trials were conducted with pregnant gilts fed one of the following 5 diets (Appendix 3): (1) 9% crude protein (CP) of maize-soybean meal, (2) as (1) + 0.2% L-lysine + 0.05% L-tryptophan, (3) 11% CP of maize-soybean meal, (4) 13% CP of maize-soybean meal, (5) 15% CP of maize-soybean meal. The experimental details of gilts and diets used in these experiments have been described above. Five gilts from each of the five gestation treatment groups (diets) were randomly selected for nitrogen balance trials during the 90th to 100th day of pregnancy. Each gilt received 2.0 kg once daily of the assigned diet.

After an adaptation period of 5 days in the metabolism cages, the pregnant gilts were subjected to 5-day nitrogen balance collecting. The collection period was from day 95 to 100 of pregnancy. The method of collecting faeces and urine were similar to that described above.

b. Nitrogen Balance of Lactating Sows

Nitrogen balance trials were carried out with lactating sows fed one of the following 5 diets (Appendix 4): (1) 12.5% CP of maize-soybean meal, (2) as (1) + 0.2% L-lysine, (3) as (2) + 0.05% DL-methionine, (4) as (3) + 0.025% L-tryptophan, (5) 15% CP of maize-soybean meal. The experimental details of lactating sows and diets employed in these experiments have been described above. Five lactating sows from each of the five lactation treatment groups (diets) were randomly selected for nitrogen balance trials between day 18 and 28 postpartum. Each sow received 4.5 kg daily in 2 equal meals of the experimental diets.

After an adaptation period of 5 days in the lactation metabolism cages, the sows were subjected to 5-day nitrogen balance collection. The collection period was from day 23 to 28 postpartum. The method of collecting faeces and urine were similar to that described above.

F. INSERTION OF CATHETER FOR BLOOD SAMPLING

One sow suckling 9 piglets on day 14 postpartum was anesthetized with 45 ml of pentobarbitone sodium (60 mg/ml) and maintained with halothane (1.5-2.5%) and oxygen (600 to 1,000 ml/min.) for catheterization. A modification of the method of Anderson and Elsley (1969) of insertion of catheter was used in this experiment. The sow was fed 5.3 kg of the low lysine basal diet (Appendix 1) daily in two equal feedings at 07.30 h and at 15.30 h, respectively. After 5 and 7 days of feeding this basal diet, 10 ml of blood were withdrawn from the sow at just before feeding (0) and 1, 2, 3, 4 and 6 hours post morning feeding.

G. BLOOD SAMPLING

1. Experiment I

Three blocks of 6 lactating sows were bled from the median ear vein 4 hours after their morning feed on days 21 and 41 post partum for parity 1 and on day 41 postpartum for parity 2. Two male and two female piglets from each sow, being withdrawn, were bled from the anterior vena cava at the age of 18 days for parity 2. The piglets were selected according to live weight approximately near the mean of the litter.

2. Experiment II

In block 1, five gilts from each of the five gestation treatment groups were bled from the median ear vein 4 hours after the once daily feed on day 100 of pregnancy, and five sows from each of the five lactation treatment groups were also bled from ear vein 4 hours after their morning meal on day 27 postpartum.

H. PLASMA PREPARATION

Blood samples (about 10 ml) were collected in heparinized tubes and centrifuged immediately. The plasma was decanted. The plasma samples of four piglets from each litter were pooled. Plasma samples were stored at -15°C until analysed.

I. DEPROTEINIZATION OF PLASMA

1. Experiment I

Plasma samples were deproteinized as described by D'Mello (1973). Blood plasma was deproteinized with 3.5% sulfosalicylic acid, and norleucine was used as internal standard.

2. Experiment II

Plasma samples were deproteinized and cleaned up according to the method of Zumwalt, Roach and Gehrke (1970). Two ml of blood plasma were placed in 50 ml centrifugal tube, 0.5 ml of 2.5 mM/ml α-amino caprylic acid was added as internal standard, 15 ml of 1% picric acid were added, and the solution was stirred with a magnetic stirrer for 5 minutes. The protein suspension was then centrifuged for 10 minutes at 3,500 rpm, and the clear supernatant liquid decanted. The aliquot of the protein-free supernatant was passed through a 0.9 x 7 cm column of Dowex 50 (100/200 mesh) resin in the hydrogen form at a rate of 1 to 2 ml/min. Five 5 to 10 ml portions of dionised water were used to wash the resin, and the effluent and washings were discarded. The amino acids were eluted from the resin with 5 separate 2-ml portions of 3N NH_4OH at 1 to 2 ml/min., followed by five 5-ml portions of deionised water at 3 ml/min. The effluent was collected in a flat-bottom flask and evaporated to dryness on a rotary evaporator at 40°C water bath. The residue was redissolved in 2.0 ml of 0.1 N HCl, transferred to a tube with a teflon-lined screw cap, tightly sealed, and refrigerated until analysis.

J. CHEMICAL ANALYSIS

1. Nitrogen Content

The nitrogen contents of the milk, feed, faeces and urine were determined by the modification of Crooke and Simpson's method (1971) in Experiment I, while Chaney and Marbach's method (1962) was used in Experiment II.

2. Milk Fat, Lactose, Total Solids, Ash and Energy

The fat content of the milk was measured by a modification of the Gerber method (British Standards Institution, 1955), and lactose content was determined by the modified Chloramine-T method (Ling, 1963). Total solids content of the milk was determined by freeze-drying. Ash content of the milk was determined by the method of the A.O.A.C. (1965). The formula suggested by Perrin (1954b) was used in the calculation of the energy value of the milk samples.

3. Plasma Urea

Automated methods of analysis were used to determine blood urea according to Fawcett and Scott (1960).

4. Amino Acids

a. Experiment I

Samples of diets and feedstuffs were hydrolyzed by the method of D'Mello (1972). Hydrolysis under nitrogen was for 6 h to ensure minimal loss of methionine and for 20 h to obtain maximum yields of other amino acids. Cystine was estimated by the method of Moore (1963), and tryptophan was not determined in this experiment. Deproteinized plasma, hydrolyzed feed and faecal samples were analysed for amino acids by ionexchange chromatography using Technicon Auto Analyser (Technicon Instruments Company Ltd., Hamilton Close, Houndmills, Basingstoke, Hants.) modified by D'Mello (1972). The modifications included the use of 2:4:6-trinitro benzenesulphonic acid as colour reagent instead of ninhydrin and of a thermostatic water bath for the development of colour at 37°C. The duration of analysis was reduced from 21 to 17 h by increasing the pumping rate of the positive displacement pump to 0.6 ml/min.

b. Experiment II

Samples of diets and feedstuffs were hydrolyzed by the method of Roach and Gehrke (1970), and the hydrolyzed samples were cleaned up according to the method of Zumwalt *et al* (1970). The samples of deproteinized plasma and hydrolyzed feeds were analysed for amino acids by gas-liquid chromatography method.

i. Preparation of Derivatives

The conversion of amino acids to the N-trifluroacetyl (N - TFA) n-butyl esters has been described by Roach and Gehrke (1969). An appropriate aliquot of sample (1-200 µg total amino acids) was pipetted into a micro reaction tube with a teflon-lined screw cap, and evaporated just to dryness by passing a stream of filtered dry N_2 gas over the sample at 100°C. Azeotropic removal of water was completed by adding 100 µl of CH_2Cl_2 and evaporating just to dryness in the above manner. To ensure complete removal of water, this step was repeated. 150 µl of n-butanol-3N HCl per 100 µl of total amino acids were added, and mixed on an ultrasonic mixer for at least 15 seconds at room temperature. The sample was esterified at 100°C for 15 minutes, and evaporated to dryness at 100°C using a stream of dry filtered N_2 gas. 60 µl of CH_2Cl_2 were added to this sample followed by 20 µl of trifluroacetic anhydride (TFAA) for each 100 µg of total amino acids, and the mixture acylated at 150°C for 5 minutes in a closed tube placed behind a safety shield. The sample was then ready for chromatography.

ii. Ethylene Glycol Adipate (EGA) Column

Stabilized grade 0.5% EGA coated on 80/100 mesh acid washed Chromosorb G which had been heat-treated was obtained from Shimazu Inc. (Japan). The EGA column was packed into 1.5m x 4mm I.D. U-shaped glass columns by partial vacuum suction of the coated support with gentle tapping of the column. Dry glass wool plugs (0.6 cm) were then placed in each end of the column to hold the packing in place. The columns were conditioned for 15 hours at 210°C with a carrier flow of about 50 ml/min pure N_2 prior to analytical use. These EGA columns were used to analyse amino acids in plasma samples. Threonine, serine and tyrosine were not detected by these columns. Then new 0.325% EGA coated on 80/100 mesh acid washed Chromosorb G which had been heat-treated as described by Gehrke, Zumwalt and Wall (1968) were prepared in our laboratory (see Appendix 7). New EGA columns showed quantitative elution, and complete separation of 17 N-TFA n-butyl esters of amino acids (excluding arginine, histidine and cystine). The amino acid contents of the diets used in Experiment II were analysed by these new EGA columns.

iii. Apparatus

A Shimazu Model 5-A (Shimazu Company Ltd., Kyoto, Japan) gas-liquid Chromatography with a four-column oven bath, two flame ionization detectors, two differential electrometers, linear temperature programming, and equipped with a recorder was used. A digital read-out integration was used for determination of peak areas.

iv. Instrumental Settings and Sample Injection

Column temperature	initial, 75°C; final 210°C
Detector temperature	250°C
Programme rate	6°C/min.
N_2 Carrier flow	50 ml/min.

iv. Instrumental Settings and Sample Injection (contd)

H_2	40 ml/min.
Air	500 ml/min.
Chart speed	10 mm/min.
Injected sample volume	1-10 µl

SECTION III: EXPERIMENT RESULTS

A. EXPERIMENT I

1. Sow Productivity

a. Sow and Litter Performance

The results obtained in the 2 parities are shown in Tables 2 and 3. Weight at breeding, total and net gains during pregnancy were generally similar for all treatments. Although quadratic responses of total sow gain were observed in the second parity, the differences were not large.

In the first lactation, sows receiving 0.79% lysine lost more weight than those receiving 0.39% and 0.69% lysine ($P < 0.05$) or the high lysine control diet ($P < 0.001$). Also, sows given 0.49 and 0.59% lysine lost more weight than those given the high lysine control diet ($P < 0.05$). However, these differences were not significant in the second lactation.

There was no significant difference in the period from weaning to mating although there was some indication that sows receiving the low lysine basal diet increased intervals from weaning to conception.

Average gains in total litter weights from 3 to 42 days of age increased linearly ($P < 0.05$) with increasing dietary lysine in both parities, and total litter gains plateaued at approximately 0.59% lysine.

In the first parity, the total intake of creep feed by the litters suckling sows on the high lysine control diet was lower ($P < 0.01$) than those given 0.49% and 0.59% lysine diets. The creep feed intake of litters from sows fed 0.69% lysine diet was also less ($P < 0.05$) than those from sows fed 0.49% lysine diet.

TABLE 2

Live-weight change of sows receiving the low protein diet during pregnancy (Experiment I)

Measurement	Treatment groups and dietary lysine during lactation						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
				Parity 1			
Breeding weight, kg	125.7	121.6	131.4	123.1	128.7	127.1	7.5
Total gestation gain, kg	31.3	34.8	34.9	33.6	33.4	31.2	17.7
Net gestation gain, kg	15.6	16.5	16.8	16.6	17.8	14.8	39.0
				Parity 2			
Breeding weight, kg	123.2	123.5	131.5	124.9	123.5	126.7	6.5
Total gestation gain[c], kg	32.0	27.7	24.8	27.3	29.5	32.1	16.5
Net gestation gain, kg	18.5	19.0	13.0	12.8	17.2	18.1	25.0

a. Coefficient of variation (%) was calculated from the error mean squares.

b. Not included in linear and quadratic comparisons.

c. Quadratic treatment effect, $P < 0.05$.

TABLE 3

Effect of lysine levels on sow and litter performance (Experiment I)

Criteria	Parity	Treatment groups and dietary lysine						C.V.[a]
		L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
Sow								
Sow weight change during lactation, kg	1[d]	- 13.1	- 18.1	- 17.1	- 13.8	- 26.1	- 6.6	49.5
	2	- 14.5	- 17.8	- 17.0	- 15.8	- 21.6	- 4.4	59.1
Sow feed consumed during lactation, kg	1	206.9	212.2	204.4	212.5	212.3	217.5	7.2
	2	241.9	223.3	216.9	230.8	227.1	230.1	7.6
Days from weaning to conception	1	26.2	13.5	10.5	5.0	19.0	12.0	
	2	32.5	24.5	14.2	10.4	19.0	3.3*	
Litter								
Number born, alive	1	9.3	9.5	10.0	9.8	8.5	9.8	18.3
	2	8.0	7.6	7.6	7.2	7.0	9.8	21.6
Average birth weight, kg	1	1.18	1.41	1.31	1.35	1.45	1.24	15.4
	2	1.26	1.41	1.41	1.42	1.37	1.22	9.5
Mean 21-day weight, kg	1[g]	4.3	5.0	4.7	4.8	5.3	4.9	10.3
	2[ce]	3.8	4.4	4.8	4.6	5.0	4.9	8.9
Mean 42-day weight, kg	1[df]	7.7	8.4	8.4	8.2	9.6	9.0	11.2
	2[df]	6.5	7.7	8.9	8.4	9.1	8.8	12.3
Total litter gain, kg	1[dg]	49.9	54.9	59.9	53.7	63.6	64.5	14.1
	2[dg]	48.0	49.4	60.1	60.7	65.2	66.8	14.5
Creep feed/litter, kg	1[d]	23.6	33.3	28.3	18.4	22.2	13.8	39.8
	2[dg]	34.3	26.0	29.7	21.8	24.8	17.6	25.5

a. Coefficient of variation (%) was calculated from the error mean squares.
b. Not included in linear and quadratic comparisons.
c. Treatment effect, $P < 0.01$.
d. Treatment effect, $P < 0.05$.
e. Linear treatment effect, $P < 0.001$.
f. Linear treatment effect, $P < 0.01$.
g. Linear treatment effect, $P < 0.05$.
* Only based on 3 animals.

In the second parity, litters from sows given the low lysine diet ate more creep feed than those from sows given the high lysine control diet or the offspring from sows given 0.69% ($P < 0.01$) or 0.79% ($P < 0.05$) lysine. Litters from sows fed 0.59% lysine diet also ate more creep feed than those from sows fed the high lysine control diet ($P < 0.05$).

b. Milk Yield and Composition

Tables 4 and 5 show the mean milk yield and the composition of milk from the sows fed various levels of lysine. A significant linear increase in milk yield occurred at weeks 2 ($P < 0.01$), 5 ($P < 0.005$) and 6 ($P < 0.10$) in the first parity, and at weeks 2 ($P < 0.05$), and 4 ($P < 0.001$) in the second parity in response to lysine supplementation. A linear effect (parity 1, $P < 0.10$; parity 2, $P < 0.01$) was also observed when the average milk yield was considered. In both parities average milk yield of sows given the high lysine control diet was significantly higher than that of sows given the low lysine basal diet ($P < 0.01$).

On increasing dietary lysine concentrations, total solids content of the milk increased linearly in samples obtained at weeks 2 ($P < 0.10$), and 5 ($P < 0.05$), and quadratically in samples obtained at weeks 2 ($P < 0.10$) and 4 ($P < 0.05$) in the first parity and week 2 ($P < 0.05$) in the second parity. However, the effect of dietary lysine on average total solids content of the milk during the six-week period was not statistically significant in the first parity, but there was a quadratically significant increase ($P < 0.05$) in milk solids in the second parity with increasing dietary lysine. The milk solids content of sows receiving the high lysine control diet were significantly higher than those of sows receiving 0.39, 0.49 and 0.79% lysine in the second parity ($P < 0.01$).

TABLE 4

Mean milk yield and composition of the first-litter gilts fed different levels of lysine during lactation (Experiment I)*

Parameter	Treatment groups and dietary lysine						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
Average milk yield[eh], kg/day	4.84	5.60	5.65	5.36	6.03	6.40	10.6
Average milk composition in fresh milk,							
Total solids[i], %	16.41	16.49	17.44	17.27	16.94	17.72	3.9
Protein[fh], %	4.59	4.81	4.99	5.06	4.75	5.33	5.7
Lactose, %	5.89	5.57	5.48	5.69	5.60	5.68	5.0
Fat[cg], %	4.93	5.29	5.68	5.67	5.84	6.60	6.1
Ash, %	0.77	0.76	0.76	0.75	0.70	0.75	10.0
Energy[dg], KJ/g	3.85	3.97	4.14	4.18	4.18	4.60	4.2

a. Coefficient of variation (%) was calculated from the error mean squares.

b. Not included in linear and quadratic comparisons.

c. Linear treatment effect, $P < 0.01$.

d. Linear treatment effect, $P < 0.05$.

e. Linear treatment effect, $P < 0.10$.

f. Quadratic treatment effect, $P < 0.10$.

g. Treatment H.C. vs others, $P < 0.001$.

h. Treatment H.C. vs others, $P < 0.05$.

i. Treatment H.C. vs others, $P < 0.10$.

* Weekly milk yield and composition of the first-litter gilt should be stored in the library as references.

TABLE 5

Mean milk yield and composition of lactating sows fed different levels of lysine (Experiment I)*

Parameter	Treatment groups and dietary lysine						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
Average milk yield[ci], kg/day	5.22	5.40	6.08	6.23	6.24	6.73	9.3
Average milk composition in fresh milk,							
Total solids[gi], %	15.32	15.97	16.81	16.53	15.75	17.68	4.5
Protein, %	3.95	4.29	4.72	4.72	4.50	5.11	-
Lactose, %	5.78	5.67	5.69	5.75	6.02	6.05	5.7
Fat[deh], %	4.60	5.20	5.61	5.38	5.01	6.31	5.0
Ash, %	0.77	0.73	0.80	0.76	0.68	0.73	8.8
Energy[ceh], KJ/g	3.57	3.83	4.10	4.02	3.87	4.52	3.5

a. Coefficient of variation (%) was calculated from the error mean squares.

b. Not included in linear and quadratic comparisons.

c. Linear treatment effect, $P < 0.01$.

d. Linear treatment effect, $P < 0.05$.

e. Quadratic treatment effect, $P < 0.001$.

f. Quadratic treatment effect, $P < 0.01$.

g. Quadratic treatment effect, $P < 0.05$.

h. Treatment H.C. vs others, $P < 0.001$.

i. Treatment H.C. vs others, $P < 0.01$.

* Milk yield and composition of lactating sows at weeks 2 and 4 should be stored in the library as references.

Average protein content of the milk increased quadratically ($P < 0.10$) with increasing dietary lysine in both parities, but milk protein of sows given the high lysine control diet was significantly higher than that of sows given 0.39, 0.49 and 0.79% lysine ($P < 0.05$).

Dietary lysine level had a marked influence on milk fat. In parity 1, fat content of milk increased linearly in samples taken at weeks 2 ($P < 0.05$), 4 ($P < 0.001$) and 6 ($P < 0.01$), and quadratically in samples taken at week 4 ($P < 0.05$). A linear effect was also noted on average fat content ($P < 0.01$) over the six-week period. In parity 2, there was a linear ($P < 0.05$) and quadratic ($P < 0.01$) increase in fat content of the milk at week 2. Average milk fat of sows receiving the high lysine control diet was significantly greater ($P < 0.001$) than that of sows receiving the other 5 diets in both parities.

Dietary lysine also had a positive effect on energy content of the milk. In the first parity, energy content of the milk increased linearly in samples obtained at weeks 3 ($P < 0.001$) and 6 ($P < 0.05$), and quadratically ($P < 0.05$) in samples obtained at week 4. Average energy content of the milk during the six-week period also increased linearly ($P < 0.05$) with increasing dietary lysine. In the second parity, linear and quadratic increase in energy content of the milk resulted at week 2 ($P < 0.01$) as dietary lysine increased. Also, there was linear ($P < 0.01$) and quadratic ($P < 0.001$) increase in the average energy content of the milk. Average milk energy of sows receiving the basal or supplemented diets was significantly lower ($P < 0.001$) than that of sows receiving the high lysine control diet in both parities.

The dietary treatment had no significant effect on lactose and ash content of the milk in either lactation periods.

2. Nitrogen Metabolism.

a. Nitrogen Balance of Pregnant Sows.

The nitrogen balance data of pregnant gilts and sows are presented in Table 6. Mean nitrogen retention of pregnant dams was 8.89 g per day. Gestation period did not have a significant effect on nitrogen excretion in faeces and urine, nitrogen retention or on apparent nitrogen digestibility.

b. Nitrogen Balance of Lactating Sows.

A summary of the balance data of the gilts and sows is presented in Table 7 and Figure 1. There was a significant linear (parity 1, $P < 0.01$) and quadratic (parity 2, $P < 0.05$) decrease in excretion of urinary nitrogen as dietary lysine levels increased, with accompanying increases in nitrogen retention, nitrogen retained as % total N intake, and biological value (BV) in both parities. Average yield of milk nitrogen also increased linearly ($P < 0.001$) in parity 1 and quadratically ($P < 0.05$) in parity 2 with increasing dietary lysine. Positive nitrogen balance was observed for sows given at least 0.59% lysine in parity 1 and given 0.49% lysine or more in parity 2. Apparent digestibility of nitrogen was not influenced by the dietary lysine, however, sows which were fed the high lysine control diet (barley-soybean meal diet) had a significantly ($P < 0.001$) higher digestibility of nitrogen than sows fed the basal or supplemented diets.

c. Digestibility of Essential Amino Acids

Mean digestibility coefficients for essential amino acids from the low lysine basal diet (barley-based diet) are presented in Table 8. The apparent nitrogen digestibility of this diet was 79.15%, which was close to the digestibility of isoleucine (77.79%), lysine (76.57%), methionine (80.84%), threonine (81.90%) and valine (77.55%). However, apparent digestibilities of arginine, histidine, leucine and phenylalanine were higher than the apparent digestibility of nitrogen in this diet.

TABLE 6

Nitrogen balance of pregnant gilts and sows fed the low protein diet (Experiment I)

Gestation period, day	Daily N (g)				Nitrogen retained % total N intake	Apparent nitrogen digestibility %
	Intake	Fecal	Urine	Retention		
			Parity 1			
85- 90	33.65	7.65	16.72	9.28	27.59	77.29
100-105	33.65	8.16	16.27	9.23	27.43	75.77
			Parity 2			
45- 55	30.74	6.41	16.51	7.82	25.44	79.15
85- 90	32.74	23.43*		9.31	28.48	-
100-105	32.74	23.92*		8.83	27.15	-
Mean**	32.70	7.41	16.50	8.89	27.22	77.40

* Including fecal and urinary nitrogen.

** Mean of 2 parities.

TABLE 7

Effect of dietary lysine on nitrogen balance of the lactating sows(Experiment I).

Parameter	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	C.V.[a]
	Treatment groups and dietary lysine						
Parity 1							
Feed N, g[h]	74.60	84.98	88.64	81.20	82.00	143.59	7.1
Faecal N[dh], g	15.38	15.46	16.41	15.22	14.66	22.50	11.1
Urine N, , g[ceh]	28.12	28.37	24.54	21.07	22.29	56.47	13.3
Retention N, [cj], g	31.10	41.14	47.69	44.93	45.04	64.62	8.4
Milk N, [gh], g	37.16	45.64	46.61	46.99	56.47	52.70	10.9
Balance N, , g	- 6.06	- 4.50	1.06	- 2.25	-11.43	12.91	335.8
Retained N% total N intake[cgi]	41.74	48.43	54.05	55.22	54.79	45.72	7.1
Biological value*[cfh], %	58.46	64.30	71.01	72.80	71.66	56.57	5.0
Apparent N digestibility,[h], %	79.50	81.78	81.48	81.17	82.14	84.33	2.1
Parity 2							
Feed N, g[h]	75.70	96.38	96.20	93.50	91.81	169.82	7.1
Faecal N,[gh], g	15.42	19.97	17.22	18.84	16.91	27.47	11.7
Urine N, ,g[ceh]	29.24	30.14	25.12	26.54	25.23	68.80	9.7
Retention N,[cgh], g	31.03	46.27	53.86	48.11	49.66	73.55	8.9
Milk N, ,[gh]g	33.16	35.68	44.29	43.29	44.55	51.25	6.0
Balance N , g	- 2.13	10.59	9.58	4.83	5.12	22.29	74.8
Retained N% total N intake[ceh]	41.26	48.06	56.03	51.42	53.99	43.25	5.6
Biological value*[cfh], %	57.67	65.44	72.29	69.07	70.59	54.52	4.7
Apparent N digestibility[h], %	79.77	79.32	81.72	79.82	81.58	83.85	2.0

* The BV data were calculated as described the modified formula of Werner and Hennig (1960).

a. Coefficient of variation was calculated from the error mean squares.

b. Not included in linear and quadratic comparisons.

c. Linear treatment effect, $P < 0.001$.

d. Linear treatment effect, $P < 0.01$.

e. Quadratic treatment effect, $P < 0.001$.

f. Quadratic treatment effect, $P < 0.01$.

g. Quadratic treatment effect, $P < 0.05$.

h. Treatment H.C. vs others, $P < 0.001$.

i. Treatment H.C. vs others, $P < 0.01$.

j. Treatment H.C. vs others, $P < 0.05$.

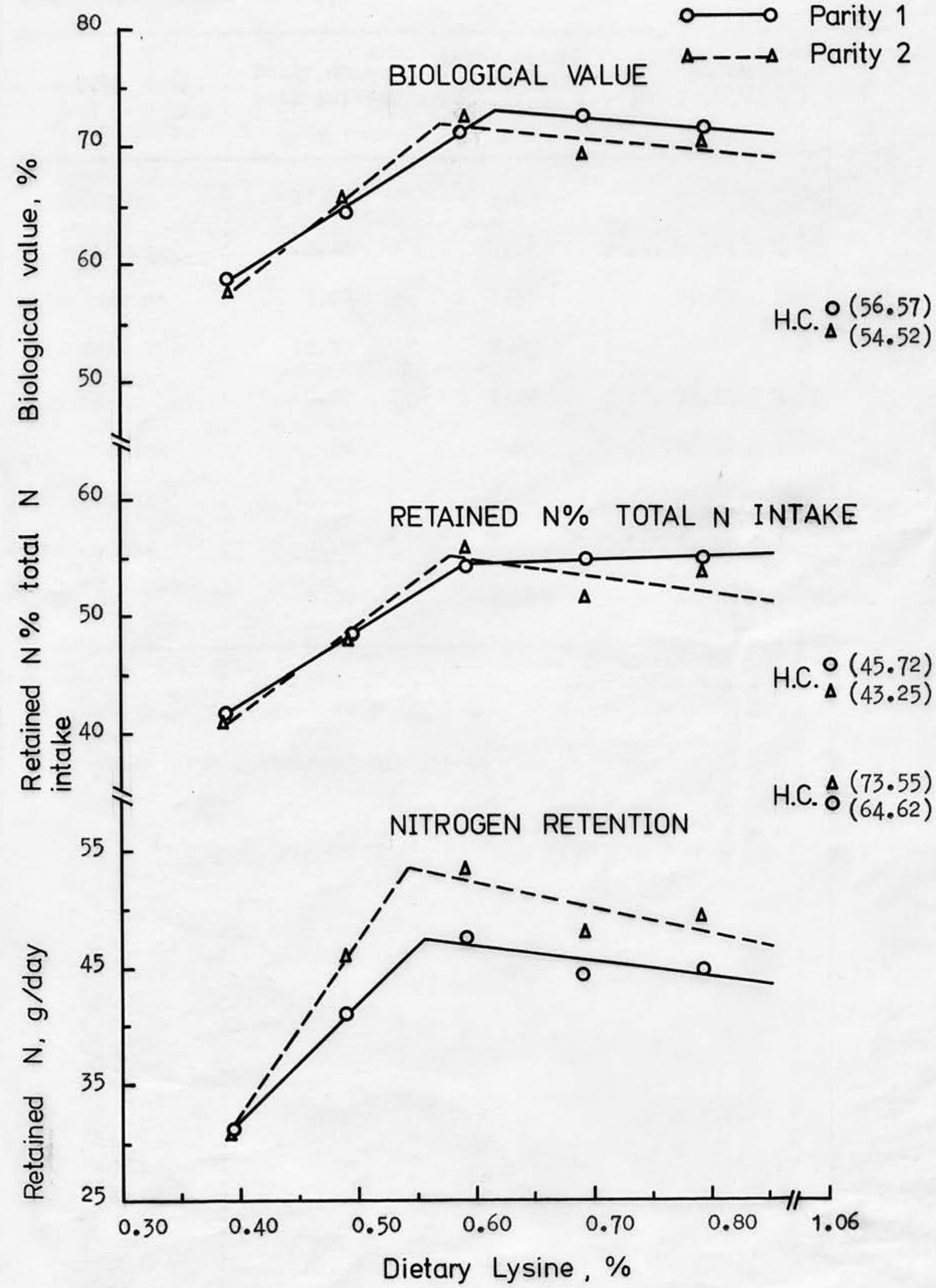

FIG. 1 EFFECT OF DIETARY LYSINE ON NITROGEN METABOLISM OF LACTATING SOWS (H.C. not included in regression comparison)

TABLE 8

Mean apparent digestibility of essential amino acids in the low lysine basal diet* (Experiment I).

Amino Acid	Daily amino acid intake, g	Daily faecal amino acid excretion, g	Apparant digestibility, ** %
Arginine	11.00	1.63	85.16 ± 1.80
Histidine	4.40	0.64	85.55 ± 2.10
Isoleucine	7.00	1.55	77.79 ± 3.26
Leucine	18.20	2.53	86.09 ± 1.84
Lysine	7.80	1.82	76.57 ± 3.39
Methionine	3.20	0.61	80.84 ± 3.00
Phenylalanine	11.20	1.72	84.67 ± 1.64
Threonine	9.20	1.67	81.90 ± 2.17
Valine	9.00	2.02	77.55 ± 2.93

* Apparent N digestibility 79.15%.

** Mean value ± standard deviation.

3. Plasma Free Amino Acids

a. Effect of Time Post-feeding on Plasma Free Amino Acid Concentrations of the Lactating Sow

The effect of time post-feeding on plasma free amino acid concentrations of the lactating sow is shown in Figure 2. The level of the essential amino acids except histidine and phenylalanine reached maximal values at 1 hour post feeding, and then declined rapidly, reaching basal levels 4 to 16 hours post-feeding. However, histidine and phenylalanine reached their maximal level at 2 hours after feeding, and their lowest levels at 4 and 16 hours, respectively, after feeding.

b. Plasma Free Amino Acid Concentrations of Lactating Sows

The effect of dietary lysine on plasma free amino acid concentrations of lactating sows are shown in Tables 9 and 10. Lactating sows were bled twice on days 21 and 41 postpartum in the first parity. There was no period effect on free plasma amino acid concentrations. Therefore, only mean values for treatment groups are presented. Plasma free lysine increased quadratically (parity 1, $P<0.001$; parity 2, $P<0.05$) and linearly (both parities, $P<0.001$) with increasing dietary lysine concentration. Lysine levels remained at a low and fairly constant level from 0.39% dietary lysine up to 0.49% dietary lysine, and then increased sharply. In the first parity, significant linear decreases were observed for threonine ($P<0.001$), serine and tyrosine ($P<0.01$), and phenylalanine ($P<0.05$), and ornithine increased linearly ($P<0.001$) as dietary lysine increased. Significant quadratic decreases were also noted for threonine, phenylalanine, cystine (on day 41), tyrosine and serine ($P<0.01$), and leucine, histidine (on day 21) and valine (on day 21) ($P<0.05$), and ornithine increased quadratically ($P<0.01$) as dietary lysine increased. It was observed that sows receiving the high lysine control diet had significantly higher levels of plasma free arginine, isoleucine, leucine, threonine, ornithine and tyrosine ($P<0.001$), and valine

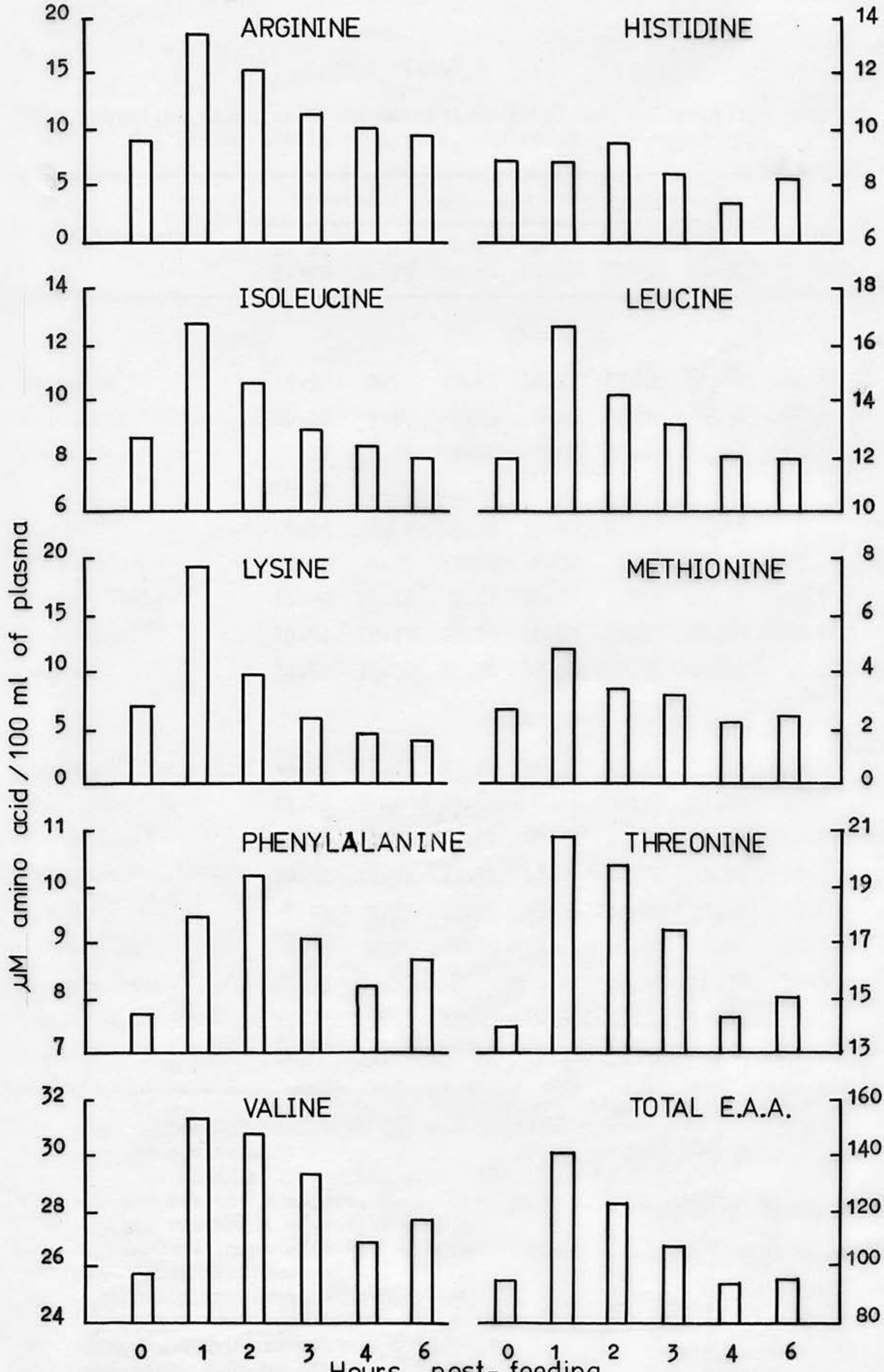

FIG. 2 EFFECT OF TIME POST-FEEDING ON PLASMA AMINO ACID CONCENTRATIONS OF LACTATING SOWS

TABLE 9

Free essential amino acid concentrations in plasma of lactating sows fed graded levels of lysine, µM/100 ml (Experiment I).

Amino acid	Treatment groups and dietary lysine						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
				Parity 1			
Arginine[i]	14.90	8.63	10.68	16.17	13.45	26.10	23.9
Histidine	10.00	9.37	7.03	8.40	8.82	9.54	16.5
Isoleucine[i]	11.17	8.46	9.02	9.60	10.62	20.14	14.2
Leucine[hi]	18.43	15.60	13.18	14.50	15.99	27.23	13.2
Lysine[cf]	6.64	7.02	14.59	33.48	45.47	19.48	15.5
Methionine	5.13	4.85	3.55	4.52	4.16	5.13	17.1
Phenylalanine[eg]	15.88	11.49	9.57	10.16	11.59	12.36	15.8
Threonine[cgi]	28.54	17.73	11.55	10.05	11.75	28.43	18.8
Valine[i]	34.80	31.20	31.00	32.00	37.50	48.20	13.7
				Parity 2			
Arginine[i]	13.00	11.95	11.32	16.31	15.55	28.88	29.3
Histidine	11.10	11.06	9.51	8.44	8.26	12.13	23.0
Isoleucine[i]	10.60	8.51	9.12	11.42	11.87	22.16	15.1
Leucine[i]	16.21	13.81	13.34	14.21	14.72	30.82	19.7
Lysine[ch]	7.91	6.73	12.28	29.36	44.06	18.09	37.2
Methionine[e]	4.54	3.95	2.68	3.60	3.10	3.78	19.2
Phenylalanine[d]	15.35	10.97	10.45	9.26	9.40	11.99	19.3
Threonine	37.27	19.00	10.97	10.66	10.51	19.08	-
Valine[j]	31.50	31.40	33.60	33.30	37.50	47.50	17.0

a. Coefficient of variation (%) was calculated from the error mean squares.
b. Not included in linear and quadratic comparisons
c. Linear treatment effect, $P < 0.001$.
d. Linear treatment effect, $P < 0.01$.
e. Linear treatment effect, $P < 0.05$.
f. Quadratic treatment effect, $P < 0.001$.
g. Quadratic treatment effect, $P < 0.01$.
h. Quadratic treatment effect, $P < 0.05$.
i. Treatment H.C. vs others, $P < 0.001$.
j. Treatment H.C. vs others, $P < 0.01$.

TABLE 10

Free non-essential amino acid concentrations in Plasma of lactating sows fed graded levels of lysine, µM/100 ml (Experiment I).

Amino Acid	Treatment groups and dietary lysine						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
				Parity 1			
Alanine[f]	83.40	96.30	79.10	84.50	90.30	58.40	8.6
Aspartic acid	4.41	3.79	3.44	3.19	3.83	3.65	25.9
Cystine	3.80	2.94	1.69	3.85	3.70	*	-
Glutamic acid[h]	68.10	52.00	46.90	47.00	50.50	29.50	28.9
Glycine	83.00	90.10	69.90	93.00	100.40	97.90	15.0
Ornithine[cef]	7.37	8.20	6.61	9.55	12.80	16.51	11.1
Serine[de]	22.69	18.83	12.96	13.94	16.70	18.82	11.6
Tyrosine[def]	12.71	9.76	7.48	8.93	8.92	13.37	10.1
				Parity 2			
Alanine	67.50	99.10	94.50	82.60	87.10	74.00	15.2
Aspartic acid	3.79	4.26	5.31	4.11	2.89	4.74	32.9
Cystine[d]	1.40	1.54	2.58	2.72	2.98	*	-
Glutamic acid[h]	39.50	51.10	57.70	40.10	44.20	28.40	24.8
Glycine[h]	74.40	97.40	103.50	108.00	90.40	121.20	18.4
Ornithine[g]	7.29	9.71	7.68	10.15	10.92	16.53	31.4
Serine	23.10	22.80	19.60	24.20	19.10	36.20	51.3
Tyrosine	13.05	9.30	9.68	9.56	9.22	11.60	32.8

a. Coefficient of variation (%) was calculated from the error mean squares.
b. Not included in linear and quadratic comparisons.
c. Linear treatment effect, $P < 0.001$.
d. Linear treatment effect, $P < 0.01$.
e. Quadratic treatment effect, $P < 0.01$.
f. Treatment H.C. vs Others, $P < 0.001$.
g. Treatment H.C. vs Others, $P < 0.01$.
h. Treatment H.C. vs Others, $P < 0.05$.
* Trace amount.

TABLE 11

Free amino acid concentrations in plasma of piglets from lactating sows fed graded levels of lysine, µM/100 ml (Experiment I).

Amino Acid	Treatment groups and dietary lysine						C.V.[a]
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H.C.[b] 1.06%	
	Essential amino acids						
Arginine	14.39	9.96	16.30	13.62	17.79	18.06	24.2
Histidine	10.11	10.74	9.95	10.13	7.48	11.87	17.6
Isoleucine	10.52	15.36	9.89	11.99	11.84	13.85	29.3
Leucine	18.94	24.37	19.82	24.15	21.21	23.92	13.4
Lysine[d]	34.80	38.60	24.20	29.00	27.00	33.30	16.5
Methionine	6.32	6.18	3.89	5.14	3.67	5.49	42.3
Phenylalanine	8.14	7.89	7.58	10.52	7.69	8.41	8.9
Threonine[f]	22.00	19.90	22.00	19.50	17.30	31.20	23.4
Valine	22.75	28.58	20.10	29.19	22.59	28.53	13.8
	Non-essential amino acids						
Alanine	113.10	116.80	101.30	94.10	83.90	113.80	23.4
Aspartic acid	2.79	3.97	2.99	3.27	2.54	2.80	34.3
Cystine[de]	2.98	1.04	2.45	1.97	4.17	2.11	27.9
Glutamic acid[d]	33.60	39.80	22.70	24.20	22.10	29.10	24.1
Glycine[c]	124.40	123.50	77.90	101.80	87.20	115.80	13.6
Ornithine	13.69	13.71	12.62	14.09	13.92	15.30	23.1
Serine	34.00	39.50	29.40	36.00	31.20	33.80	20.1
Tyrosine[d]	7.97	9.73	9.36	12.57	13.09	12.58	26.8

a. Coefficient of variation (%) was calculated from the error mean squares.
b. Not included in linear and quadratic comparisons.
c. Linear treatment effect, $P < 0.01$.
d. Linear treatment effect, $P < 0.05$.
e. Quadratic treatment effect, $P < 0.01$.
f. Treatment H.C. vs others, $P < 0.05$.

($P < 0.01$) than those receiving the basal or supplemented diets, but glutamic acid was lower ($P < 0.05$) for the high lysine control group. In the second parity, plasma phenylalanine and cystine ($P < 0.01$), and methionine ($P < 0.05$) decreased linearly as the dietary lysine increased. Sows given the high lysine control diet had significantly higher levels of plasma arginine, isoleucine, leucine ($P < 0.001$), and valine and ornithine ($P < 0.01$) than those given the other 5 diets, but glutamic acid and glycine were markedly lower ($P < 0.05$) for the high lysine control group.

c. Plasma Free Amino Acid Concentrations of Piglets

The plasma free amino acid concentrations of the piglets from lactating sows fed different levels of dietary lysine are shown in Table 11. Dietary lysine intake of the sow did not affect the pattern and the plasma free amino acid concentration of the offspring although individual differences were observed. No firm conclusion can be drawn from these data, but they are sufficiently interesting and warrant further study. However, significant linear decreases were observed for plasma glycine ($P < 0.01$), cystine, lysine and glutamic acid ($P < 0.05$). The quadratic effect was also significant for cystine ($P < 0.05$).

B. EXPERIMENT II

1. Sow Productivity

Twenty-two and twelve litters were lost from parities 1 and 2, respectively. The treatment means are presented in the Tables 12-19 which exclude calculated missing values. The disposal of sows in this experiment at the end of parity 2 is shown in Appendix 8. On the limited evidence available, there is little to indicate that these losses were related to the treatments.

An investigation into the occurrence of pregnancy x lactation treatment interactions showed that these were rarely significant and no major pattern of interactions was detected. In each of the two parities, all the variables measured, therefore, were confined to the main effects of treatments measured by their means.

a. Sow Weight Changes

As shown in Table 12, both total and net weight gains of dams fed the 9% CP diet supplemented with both 0.2% L-lysine and 0.05% L-tryptophan were significantly ($P < 0.001$) greater than those of dams fed the 9% CP diet alone during gestation in both parities. Increase in the level of dietary protein during pregnancy increased linearly (both parities, $P < 0.001$) in both total and net weight gains of dams and quadratically in both total weight gain (parity 1, $P < 0.05$; parity 2, $P < 0.01$) and net weight gain of dams (parity 1, $P < 0.01$; parity 2, $P < 0.05$). Both total and net weight gains of sows given the 11% CP diet were similar to those of sows given 9% CP diet supplemented with both lysine and tryptophan in both parities. Weight loss of sows during lactation tended to increase with increasing level and quality of dietary protein during pregnancy (parity 1, linear trend, $P < 0.01$), although this evidence did not reach significance ($P > 0.05$) in parity 2.

As shown in Table 13, levels of crude protein or amino acid supplementations with the basal diet for lactation did not influence on both total and net weight gains of sows during pregnancy, and on weight loss of sows during lactation in both parities ($P > 0.05$).

b. Litter Performance at Birth

Total and alive number of pig born were not influenced by the level of crude protein and amino acid supplementations in diet during pregnancy and lactation, nor were average birth weights of total pigs and live pigs born (Tables 12 and 13).

c. Litter Performance to Weaning

As shown in Table 14, number of litters weaned as % total litters

TABLE 12:

Main effects of protein levels and amino acid supplementations in gestation diets on sow weight changes and parturition data (Experiment II).

Parameter	Gestation Treatment Groups					Significant Difference			
	1	2	3	4	5				
	9% CP	As 1 + 0.2% L-lys. + 0.05% L-tryp.	11% CP	13% CP	15% CP	Treat.2 vs. Others	Lin.	Qua.	C.V.(%)
"PARITY 1"									
No. Gilts Farrowing	40	40	40	40	40				
Sow Weight Changes, kg									
At mating	115.9	114.0	114.3	118.4	118.7	N.S.	N.S.	N.S.	12.54
Total gain in gestation	38.4	45.2	46.7	49.3	53.4	N.S.	***	*	15.16
Net gain in gestation	25.2	32.7	34.6	36.0	39.7	N.S.	***	**	19.33
Lactation weight loss	3.3	5.0	7.6	7.3	9.7	N.S.	***	N.S.	134.65
No. Pigs Born/Litter									
Total	8.4	8.8	8.2	8.4	8.9	N.S.	N.S.	N.S.	28.77
Alive	7.8	8.4	7.8	7.9	8.6	N.S.	N.S.	N.S.	28.89
Birth Weight (total pigs born), kg	1.30	1.35	1.36	1.33	1.36	N.S.	N.S.	N.S.	15.69
Birth Weight (live pigs), kg	1.32	1.36	1.34	1.37	1.37	N.S.	N.S.	N.S.	15.07
"PARITY 2"									
No. Sows Farrowing	36	38	36	36	37				
Sow Weight Changes, kg									
At mating	131.4	135.6	136.3	141.9	143.7	N.S.	N.S.	N.S.	10.73
Total gain in gestation	39.8	47.2	48.3	50.0	50.7	N.S.	***	**	15.83
Net gain in gestation	26.3	34.2	32.9	35.7	37.2	N.S.	***	*	21.98
Lactation weight loss	8.4	12.3	12.0	11.3	10.8	N.S.	N.S.	N.S.	72.28
No. Pigs Born/Litter									
Total	8.8	9.1	9.9	10.0	9.3	N.S.	N.S.	N.S.	30.30

/contd.

/contd.

Parameter	Gestation Treatment Groups					Significant Difference			C.V.(%)
	1	2	3	4	5				
	9% CP	As 1 + 0.2% L-lys. + 0.05% L-tryp.	11% CP	13% CP	15% CP	Treat.2 vs. Others	Lin.	Qua.	
"PARITY 2"									
Alive	8.2	8.7	9.6	9.4	9.0	N.S.	N.S.	N.S.	29.64
Birth Weight (total pigs born), kg	1.50	1.46	1.41	1.44	1.43	N.S.	N.S.	N.S.	14.86
Birth Weight (live pigs), kg	1.54	1.49	1.43	1.48	1.46	N.S.	N.S.	N.S.	14.79

TABLE 13

Main effects of protein levels and amino acid supplementations in lactation diets on sow weight changes and parturition data (Experiment II).

PARAMETER	Lactation Treatment Groups 1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15% CP	Significant Difference: Treat.1 vs. Others	Among Others	C.V.(%)
"PARITY 1"								
No. Gilts Farrowing	40	40	40	40	40			
Sow Weight Changes, kg								
At mating	116.7	115.8	118.4	115.3	115.0	N.S.	N.S.	12.54
Total gain in gestation	45.3	46.5	44.4	47.5	49.2	N.S.	N.S.	15.16
Net gain in gestation	32.6	34.1	31.4	34.8	35.3	N.S.	N.S.	19.33
Lactation weight loss	7.9	7.0	6.2	5.3	6.5	N.S.	N.S.	134.65
No. Pigs Born/Litter								
Total	8.6	8.7	8.2	8.7	8.6	N.S.	N.S.	28.77
Alive	8.2	8.2	7.9	8.1	8.0	N.S.	N.S.	28.89
Birth Weight (total pigs born), kg	1.35	1.31	1.35	1.32	1.36	N.S.	N.S.	15.69
Birth Weight (live pigs), kg	1.36	1.33	1.35	1.33	1.38	N.S.	N.S.	15.07
"PARITY 2"								
No. Sows Farrowing	35	38	36	37	37			
Sow Weight Changes, kg								
At mating	133.8	136.9	138.5	139.1	140.8	N.S.	N.S.	10.37
Total gain in gestation	47.8	46.5	46.4	48.0	47.4	N.S.	N.S.	15.83
Net gain in gestation	34.4	33.0	32.9	33.3	33.0	N.S.	N.S.	21.98
Lactation weight loss	10.3	11.8	10.0	12.5	10.0	N.S.	N.S.	72.28
No. Pigs Born/Litter								
Total	9.2	9.0	9.6	9.3	10.0	N.S.	N.S.	30.30
Alive	9.0	8.6	9.1	8.7	9.4	N.S.	N.S.	29.64
Birth Weight (total pigs born), kg	1.50	1.45	1.43	1.50	1.38	N.S.	N.S.	14.86
Birth Weight (live pigs), kg	1.52	1.47	1.46	1.53	1.42	N.S.	N.S.	14.79

TABLE 14

Weaned Litters as % Total Litters Farrowed (Experiment II).

	Pregnancy Treatment Groups	Parity	Lactation Treatment Groups 1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15% CP	Pregnancy Treatment Effect
1.	9% CP	1	75.0	75.0	75.0	75.0	87.5	77.5
		2	100	85.7	85.7	87.5	85.3	88.9
2.	As 1. + 0.2% L-lys. + 0.05% L-tryp.	1	100	100	100	75.0	87.5	92.6
		2	100	71.4	100	100	100	94.7
3.	11% CP	1	87.5	87.5	87.5	100	73.0	87.5
		2	83.3	100	100	100	87.5	94.4
4.	13% CP	1	87.5	87.5	100	87.5	100	92.5
		2	100	75.0	100	100	100	97.7
5.	15% CP	1	100	87.5	100	100	87.5	95
		2	100	100	100	100	75.0	93.4
Lactation Treatment		1	90.0	87.5	92.5	87.5	87.5	89.0
Effect		2	97.1	86.5	87.2	97.3	89.4	93.4

farrowed was the lowest percentage in pregnant sows fed the 9% CP diet alone in both parities. It was also observed that diarrhoea occurred in litters from sows receiving the 9% CP gestation diet alone more than those from sows receiving the other diets. The pregnant sows given the 9% CP diet alone had a lower ($P < 0.05 \sim 0.001$) litter size at weaning than those given the other 4 diets in both parities (Table 15). Increased levels of pregnant dietary protein resulted in linear (both parities, $P < 0.001$) and quadratic (parity 2, $P < 0.01$) increases in weaned litter size. In the first parity, significant linear ($P < 0.001$) increases were observed for litter weights on days 10 and 28 (weaning) of age, and for average weaned-pig-weights and net litter gains as the level of pregnant dietary protein increased. Significant quadratic increases were also noted for litter weights on days 10 ($P < 0.01$) and 28 ($P < 0.05$) of age, and for net litter gain ($P < 0.05$) as the level of dietary protein increased. In the second parity, both litter weight at weaning ($P < 0.001$) and net litter gain ($P < 0.01$) increased linearly as the pregnant dietary protein increased. Significant quadratic increases were observed for litter weight at weaning ($P < 0.05$) and for net litter gain ($P < 0.01$) as the level of dietary protein increased. The net gains of litters from sows fed the 9% CP pregnant diet supplemented with both lysine and tryptophan were significantly greater (parity 1, $P < 0.001$; parity 2, $P < 0.01$) than those from sows fed the 9% CP diet alone.

In the first parity net gains of litter from pregnant gilts receiving the 15% CP diet tended to be higher than those from pregnant gilts receiving 9% CP diet supplemented with both lysine and tryptophan, and the 11 and 13% CP diets. However, there were no significant differences between these treatment groups. Both weaning weight and net gain of litter from pregnant sows given the 9% CP diet were significantly lower ($P < 0.001$) than those from pregnant sows given the other 4 diets.

TABLE 15

Main effects of protein levels and amino acid supplementation in gestation diets on performance of piglets (Experiment II).

Parameter	Treatment Groups					Significant Difference			
	1	2	3	4	5				
	9% CP	0.2% L-lys.+ 0.05% L-tryp.	11% CP	13% CP	15% CP	Treat.2 vs. Others	Lin.	Qua.	C.V.(%)
					"PARITY 1"				
No. Pigs/Litter									
At day 4	7.2	7.7	7.7	7.8	8.0	N.S.	N.S.	N.S.	13.34
At day 10	6.9	7.5	7.5	7.7	8.0	N.S.	N.S.	N.S.	14.57
At weaning	6.8	7.5	7.4	7.7	8.0	N.S.	***	N.S.	15.02
Litter Weight, kg									
At day 4	11.4	13.2	12.7	13.4	13.6	N.S.	N.S.	N.S.	18.77
At day 10	15.1	18.4	18.8	20.2	20.6	N.S.	***	**	20.75
At weaning	30.8	39.9	38.9	41.5	44.2	N.S.	***	*	16.20
Average Pig Weight at Weaning, kg	4.59	5.40	5.30	5.43	5.62	N.S.	***	N.S.	14.21
Net Litter Gain, kg	20.0	27.2	26.7	28.1	30.6	N.S.	***	*	18.40
					"PARITY 2"				
No. Pigs/Litter									
At day 4	8.5	8.9	8.9	9.0	8.9	N.S.	N.S.	N.S.	14.26
At day 10	8.1	8.8	8.8	8.8	8.7	N.S.	N.S.	N.S.	14.69
At weaning	7.7	8.5	8.7	8.8	8.7	N.S.	***	**	14.28
Litter Weight, kg									
At day 4	15.8	16.9	16.3	16.8	16.0	N.S.	N.S.	N.S.	22.85
At day 10	23.7	25.2	25.0	26.2	24.2	N.S.	N.S.	N.S.	18.90
At weaning	42.8	48.1	49.5	51.8	48.6	N.S.	***	*	16.65
Average Pig Weight at Weaning, kg	5.56	5.67	5.69	5.89	5.59	N.S.	N.S.	N.S.	14.85
Net Litter Gain, kg	28.3	32.6	33.5	35.3	33.2	N.S.	**	**	20.22

In both parities, no significant differences were observed among lactation treatments for number of pigs on days 4, 10 and 28 of age, for litter weight on days 4, 10 and 28 of age, and for average weaned pig weight and net litter gain (Table 16). Lactating sows fed the basal diet resulted in lower litter-weaned weight and net litter gain than those fed the high protein control diet and the basal diet supplemented with lysine, and with combination of lysine, methionine and tryptophan, however, the differences did not reach significance ($P > 0.05$) in both parities.

d. Milk Composition

As shown in Table 17, the composition of milk samples from sows fed different lactation diets were not significantly different ($P > 0.05$).

e. Breeding Regularity and Fertility

Gilts and sows given the 9% CP diet with or without both lysine and tryptophan additions in pregnancy returned to effective service 10 and 14 days, respectively, later than those given the 15% CP diet in the first parity (Table 18). There was also a linear ($P < 0.01$) decrease in interval between weaning and effective service with increasing level of dietary protein during pregnancy in parity 1. Sows fed the 9% CP diet with both lysine and tryptophan supplementations during gestation returned to effective service 8 to 6 days later than those fed the 13% ($P < 0.01$) and 15% ($P < 0.05$) CP diets, respectively, in the second parity. However, the weaning to mating intervals of gestation sows fed the 9 and 11% CP diets were not significantly different from those fed the 13 and 15% CP diets. Sow feed consumption during pregnancy and lactation, and creep feed intake per litter were not affected by the gestation treatment. However, sow feed consumption during weaning to effective service had similar trend to the effect of

TABLE 16

Main effects of protein levels and amino acid supplementations in lactation diets on performance of piglets (Experiment II).

Parameter	Lactation Treatment Groups					Significant Difference		C.V.(%)
	1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15% CP	Treat.1 vs. Others	Among Others	
					"PARITY 1"			
No. Pigs/Litter								
At day 4	7.6	7.9	7.9	7.6	7.6	N.S.	N.S.	13.34
At day 10	7.4	7.6	7.9	7.3	7.5	N.S.	N.S.	14.57
At weaning	7.3	7.5	7.8	7.3	7.4	N.S.	N.S.	15.02
Litter Weight, kg								
At day 4	12.7	13.4	13.1	12.7	12.8	N.S.	N.S.	18.77
At day 10	18.1	19.5	19.1	18.7	18.4	N.S.	N.S.	20.75
At weaning	37.6	40.6	39.7	39.7	39.2	N.S.	N.S.	16.20
Average Pig Weight at Weaning, kg	5.19	5.35	5.09	5.51	5.35	N.S.	N.S.	16.21
Net Litter Gain, kg	25.4	27.7	26.9	27.1	26.8	N.S.	N.S.	18.40
					"PARITY 2"			
No. Pigs/Litter								
At day 4	8.8	8.8	9.0	8.6	9.1	N.S.	N.S.	14.26
At day 10	8.6	8.6	8.8	8.4	8.7	N.S.	N.S.	14.69
At weaning	8.5	8.4	8.6	8.4	8.6	N.S.	N.S.	14.28
Litter Weight, kg								
At day 4	16.2	16.2	16.2	16.6	16.5	N.S.	N.S.	22.85
At day 10	24.5	23.7	24.8	25.8	25.4	N.S.	N.S.	18.90
At weaning	46.9	47.3	47.5	48.4	51.0	N.S.	N.S.	16.65
Average Pig Weight at Weaning, kg	5.52	5.63	5.54	5.79	5.91	N.S.	N.S.	14.85
Net Litter Gain, kg	31.3	32.1	32.2	32.2	35.1	N.S.	N.S.	20.22

TABLE 17

Effect of protein levels and amino acid supplementations in lactation diets on sow's milk composition (Experiment II)*.

Parameter	Lactation Treatment Groups					Significant Difference	C.V.(%)
	1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 H.C.		
Total Solids, %	16.46	17.15	16.95	17.98	17.12	N.S.	6.62
Protein, %	5.29	5.34	5.64	5.69	5.38	N.S.	11.16
Lactose, %	5.01	4.99	4.86	5.07	5.12	N.S.	8.88
Fat, %	4.89	5.58	4.96	6.02	6.07	N.S.	25.23
Ash, %	0.87	0.86	0.84	0.84	0.83	N.S.	11.28
Energy,KJ/g	3.84	4.09	3.90	4.35	4.32	N.S.	12.78

* Average milk composition in fresh milk.

TABLE 18

Main effects of protein levels and amino acid supplementations in gestation diets on breeding regularity and feed consumption of sows (Experiment II).

Parameter	Gestation Treatment Groups					Significant Difference			C.V.(%)
	1	2	3	4	5				
	9% CP	As 1 + 0.2% L-lys.+ 0.05% L-tryp.	11% CP	13% CP	15% CP	Treat.2 vs. Others	Lin.	Qua.	
"PARITY 1"									
Gestation Length, day	113.3	114.3	113.9	114.2	113.5	N.S.	N.S.	N.S.	2.06
Lactation Length, day	28.0	28.0	28.0	28.0	28.0				
Interval between Weaning and Effective Service, day	34.1	29.5	31.5	23.9	19.5	N.S.	**	N.S.	97.80
Reproductive Cycle Length, day	175.4	171.8	173.4	166.1	161.0				
Feed Consumption, kg									
Pregnancy	226.4	227.6	226.9	227.2	226.8	N.S.	N.S.	N.S.	1.54
Lactation	107.4	106.0	107.8	109.5	110.4	N.S.	N.S.	N.S.	5.70
Weaning to service	68.3	59.0	63.1	47.8	39.0	N.S.	**	N.S.	97.80
Creep feed	1.20	1.24	1.38	1.34	1.31	N.S.	N.S.	N.S.	27.00
Total	403.3	393.84	399.18	385.84	377.51				
"PARITY 2"									
Gestation Length, day	114.0	113.9	113.8	113.7	114.5	N.S.	N.S.	N.S.	1.73
Lactation length, day	28.0	28.0	28.0	28.0	28.0				
Interval between Weaning and Effective Service, day	12.5	15.3	10.0	7.1	9.5	*	N.S.	N.S.	108.2
Reproductive Cycle Length, day	154.5	157.2	151.8	148.8	152.0				
Feed Consumption, kg									
Pregnancy	228.5	228.2	227.8	227.7	227.7	N.S.	N.S.	N.S.	1.75
Lactation	116.4	116.4	114.0	116.0	113.7	N.S.	N.S.	N.S.	6.25
Weaning to service	25.4	30.6	20.0	14.1	19.1	*	N.S.	N.S.	107.30
Creep feed	1.37	1.48	1.52	1.54	1.51	N.S.	N.S.	N.S.	31.13
Total	371.67	376.68	363.32	359.34	362.01				

TABLE 19

Main effects of protein and amino acid supplementations in lactation diets on breeding regularity and feed consumption of sows (Experiment II).

Parameter	Lactation Treatment Groups 1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 H.C.	Significant Difference Treat.1 vs. Others	Among Others	C.V.(%)
"PARITY 1"								
Gestation Length, day	113.2	114.0	114.2	114.0	113.8	N.S.	N.S.	2.06
Lactation Length, day	28.0	28.0	28.0	28.0	28.0			
Interval between Weaning and Effective Service, day	27.4	29.7	26.5	27.7	27.3	N.S.	N.S.	97.8
Reproductive Cycle Length, day	168.6	171.7	168.7	169.7	169.1			
Feed Consumption, kg								
Pregnancy	226.7	226.9	227.6	227.1	226.7	N.S.	N.S.	1.54
Lactation	108.3	108.3	108.5	108.3	107.9	N.S.	N.S.	5.70
Weaning to service	54.8	59.3	53.0	55.4	54.7	N.S.	N.S.	97.80
Creep feed	1.28	1.33	1.29	1.29	1.29	N.S.	N.S.	27.00
Total	391.08	395.83	390.39	392.59	390.59			
"PARITY 2"								
Gestation Length, day	114.2	114.1	113.9	113.9	113.8	N.S.	N.S.	1.73
Lactation Length, day	28.0	28.0	28.0	28.0	28.0			
Interval between Weaning and Effective Service, day	10.0	12.7	10.5	9.9	11.4	N.S.	N.S.	108.20
Reproductive Cycle Length, day	152.2	154.8	152.4	151.8	153.2			
Feed Consumption, kg								
Pregnancy	228.5	228.2	227.8	227.8	227.7	N.S.	N.S.	1.75
Lactation	115.4	115.2	115.2	115.2	114.3	N.S.	N.S.	6.25
Weaning to service	20.1	25.8	21.1	19.7	22.8	N.S.	N.S.	107.3
Creep feed	1.57	1.38	1.41	1.40	1.67	N.S.	N.S.	31.13
Total	365.57	370.58	365.51	364.14	366.47			

gestation treatments on the interval between weaning and effective service in both parities. Breeding regularity, sow feed consumption and creep feed intake per litter were also not influenced by the lactation treatment in both parities (Table 19).

2. Nitrogen Metabolism

a. Nitrogen Balance of Pregnant Gilts

The nitrogen balance data of pregnant gilts is presented in Table 20. Increasing level of dietary protein caused a linear increase in daily faecal nitrogen excretion ($P < 0.05$). Excretion of urinary nitrogen increased significantly ($P < 0.05$-0.001) as dietary protein level increased. Regression analysis of urinary N values yielded a significant linear trend ($P < 0.001$).

Supplementation of the 9% CP diet with both 0.2% L-lysine and 0.05% L-tryptophan significantly ($P < 0.05$) increased nitrogen retention in pregnant gilts. A value of 47% increase in nitrogen retention resulted. Regression of nitrogen retention on daily nitrogen intake (excluding treatment 2) was significantly linear ($P < 0.001$), but was not significantly ($P > 0.05$) quadratic. The 9% CP diet fed pregnant gilts decreased significantly ($P < 0.001$) nitrogen retention as % total N intake compared with that of sows fed the adding both lysine and tryptophan diet or the higher protein diets. Nitrogen retention as % of total N intake increased with increasing dietary protein level, and reached a maximum with the 13% CP diet fed.

b. Nitrogen Balance of Lactating Sows

The nitrogen balance data of lactating sows is presented in Table 21. There was a significant ($P < 0.01$) decrease in excretion of the urinary nitrogen by the supplementation of the basal diet with 0.2% L-lysine, or with 0.2% L-lysine and 0.05% DL-methionine, or with

TABLE 20

Effect of protein levels and amino acid supplementations in diets on nitrogen balance of pregnant gilts (Experiment II).

Parameter	Gestation Treatment Groups					C.V.*
	1	2**	3	4	5	
	9% CP	As 1 + 0.2% L-lys. +0.05% L-tryp.	11% CP	13% CP	15% CP	%
Feed N, g	29.63	31.43	37.60	46.17	50.44	12.66
Faecal N, g	7.02^{b}	6.78^{b}	7.61^{c}	8.29^{d}	8.90^{e}	7.47
Urine N, g	15.30^{b}	13.91^{b}	18.41^{c}	22.08^{d}	24.44^{e}	11.97
Retention N, g	7.30^{a}	10.76^{b}	11.58^{b}	15.96^{d}	17.10^{e}	8.44
Retained N as % total N intake	24.68^{b}	34.42^{de}	30.96^{d}	34.57^{de}	34.00^{de}	11.23
Apparent nitrogen digestibility, %	76.30^{b}	78.43^{bc}	79.76^{c}	82.02^{d}	82.35^{de}	3.53

* Coefficient of variation was calculated from the error mean squares.

** Results presented for treatment 2 in this table were not included in regression analysis.

a,b,c Means with different superscripts differ significantly ($P<0.05$).

c,d Means with different superscripts differ significantly ($P<0.05$).

d,e Means with different superscripts differ significantly ($P<0.05$).

a,d Means with different superscripts differ significantly ($P<0.01$).

b,d Means with different superscripts differ significantly ($P<0.01$).

c,e Means with different superscripts differ significantly ($P<0.01$).

a,e Means with different superscripts differ significantly ($P<0.001$).

b,e Means with different superscripts differ significantly ($P<0.001$).

Where double superscripts appear, use the second letter for statistical comparisons.

TABLE 21

Effect of protein levels and amino acid supplementations in diets on nitrogen balance of lactating sows (Experiment II).

Parameter	Lactation Treatment Groups					C.V.*
	1	2	3	4	5	
	L.B.	As 1 + 0.2% L-lys.	As 2 + 0.05 % DL-meth.	As 3 + 0.025% L-tryp.	H. C.	%
Feed N, g	91.11	85.76	92.92	92.50	106.80	7.37
Faecal N, g	12.79	11.78	15.77	11.53	15.74	20.77
Urine N, g	31.73[d]	20.48[b]	23.11[bc]	25.86[bd]	31.73[d]	22.37
Retention N, g	46.61[b]	53.50[c]	54.04[c]	55.12[c]	59.32[cd]	9.77
Retained N % total N intake, %	51.27[b]	62.39[cd]	58.44[c]	59.60[c]	55.50[bc]	9.34
Apparent N digestibility, %	85.95	86.31	83.02	87.54	85.24	7.58

* Coefficient of variation (%) was calculated from the error mean squares.

The footnotes of statistically significant differences are similar to those described in Table 20.

0.2% L-lysine and 0.05% DL-methionine and 0.025% L-tryptophan, therefore, with accompanying increase in nitrogen retention ($P < 0.05$) and nitrogen retained as % total N intake ($P < 0.05-0.01$).

The nitrogen retention of lactating sows fed the basal diet supplemented with lysine, or with lysine and methionine or with lysine, methionine and tryptophan was not significantly ($P > 0.05$) less than that of sows fed the high protein control diet (15% CP). However, the sows receiving the high protein control diet retained nitrogen as % total N intake less than those sows receiving the basal diet supplemented with amino acids.

3. Plasma Free Amino Acids and Urea

a. Pregnant Gilts

Results of the analysis of free amino acid and urea concentrations in blood plasma of pregnant gilts are shown in Table 22. With the exception of lysine, the average of plasma free amino acid levels of gestation gilts given the 9% CP diet supplemented with 0.2% L-Lysine and 0.05% L-tryptophan decreased significantly compared with those of gilts given the 9% CP diet (maize as main protein source) alone (valine, glutamic acid, $P < 0.001$; isoleucine, leucine, $P < 0.01$; phenylalanine, alanine, glycine, proline, $P < 0.05$). Plasma lysine of pregnant gilts fed the 9% CP diet supplemented with both lysine and tryptophan increased sharply ($P < 0.001$) compared with those of gilts fed the 9% CP diet alone, but plasma urea concentrations is in contrast to the plasma lysine response ($P < 0.01$). Pregnant gilts receiving 2% equal-space increment in dietary protein from the lowest 9% CP diet to the highest 15% CP diet had no consistence of increasing levels of blood free amino acids except lysine. Plasma lysine remained at a low and fairly constant level from those fed the 9% CP diet alone up to the 11% CP diet, and then increased sharply ($P < 0.01$). Blood urea increased as dietary protein

TABLE 22

Effect of protein levels and amino acid supplementations in diets on free amino acid and urea concentrations in blood plasma of pregnant gilts (Experiment II).

Parameter	Gestation Treatment Groups					C.V.*
	1	2	3	4	5	
	9% CP	As 1 + 0.2% L-lys. +0.05% L-tryp.	11% CP	13% CP	15% CP	
Plasma free essential amino acids, µM/100 ml						
Isoleucine	19.75^{d}	8.81^{b}	19.56^{d}	18.01^{d}	20.07^{de}	27.66
Leucine	36.42^{cd}	26.10^{b}	32.64^{c}	34.88^{c}	36.00^{cd}	15.75
Lysine	10.86^{b}	22.99^{de}	10.99^{b}	18.34^{cd}	17.06^{c}	23.57
Methionine	4.21^{b}	3.94^{b}	3.98^{b}	4.63^{b}	6.81^{d}	21.80
Phenylalanine	13.81^{c}	9.96^{b}	14.05^{cd}	14.04^{cd}	14.44^{cd}	18.18
Valine	35.74^{de}	18.79^{b}	29.45^{d}	31.97^{de}	32.88^{de}	18.34
Plasma free non-essential amino acids, µM/100 ml						
Alanine	139.49^{c}	83.28^{b}	121.66^{bc}	87.65^{b}	82.91^{b}	32.81
Aspartic acid	8.93^{bc}	6.52^{b}	9.38^{bc}	10.85^{cd}	13.32^{de}	30.07
Glutamic acid	76.95^{de}	44.13^{b}	78.61^{de}	75.36^{de}	71.59^{d}	19.94
Glycine	247.49^{d}	158.61^{bc}	179.61^{bc}	127.58^{b}	147.31^{bc}	36.09
Ornithine	20.66^{bc}	17.65^{b}	18.49^{bc}	19.10^{bc}	27.43^{d}	21.91
Proline	104.72^{cd}	57.37^{b}	82.29^{bc}	64.48^{b}	74.29^{bc}	27.27
Plasma urea, mg/100 ml						
	22.69^{cd}	15.63^{b}	20.40^{cd}	21.42^{cd}	24.37^{de}	20.85

* Coefficient of variation (%) was calculated from the error mean squares.

The footnotes of statistically significant differences are similar to those described in Table 20.

increased from 11 to 15% CP, although the increases are not significant ($P > 0.05$).

b. Lactating Sows

The results of the analysis of plasma free amino acid and urea levels of lactating sows are shown in Table 23. With the exception of methionine, plasma free essential amino acid levels of lactating sows given the high protein control diet (H.C.) tended to be higher than those of sows given the basal diet (L.B.). However, plasma leucine, phenylalanine and valine were not significantly different among the 5 treatments ($P > 0.05$). Plasma isoleucine decreased significantly ($P < 0.05$) as the basal diet supplemented with 0.2% L-lysine, or with 0.2% L-lysine and 0.05% DL-methionine, or with 0.2% lysine, 0.05% DL-methionine and 0.025% L-tryptophan. Plasma lysine increased significantly ($P < 0.05$-0.001) on adding to the basal diet lysine, or lysine and methionine, or lysine, methionine and tryptophan. However, inclusion of added lysine with methionine, or with methionine and tryptophan ($P < 0.05$) resulted in greater levels of free lysine in plasma than obtained from feeding the basal diet supplemented with lysine. Plasma urea was lower for sows given the basal diet supplemented with lysine than for those given the basal diet, although the difference is not significant ($P > 0.05$). Plasma urea was similar to those sows fed the basal diet supplemented with lysine, or with lysine and methionine, or with lysine, methionine and tryptophan.

TABLE 23

Effect of protein levels and amino acid supplementations in lactation diets on free amino acid and urea concentrations in blood plasma of lactating sows (Experiment II).

Amino Acid and urea	Lactation Treatment Groups					C.V.*
	1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 H.C.	
Plasma free essential amino acids, µM/100 ml						
Isoleucine	12.18^{c}	8.28^{bc}	5.66^{b}	6.65^{b}	13.13^{c}	45.80
Leucine	23.26	23.98	19.14	20.39	27.20	27.06
Lysine	10.32^{b}	18.44^{c}	21.45^{cd}	24.92^{d}	17.32^{c}	26.87
Methionine	5.73	4.56	5.56	6.21	4.98	26.08
Phenylalanine	13.19	10.27	11.32	12.83	15.22	21.25
Valine	22.61	21.37	13.65	17.54	25.15	41.42
Plasma free non-essential amino acids, µM/100 ml						
Alanine	88.23	107.00	62.50	66.46	82.29	32.27
Aspartic acid	13.57	11.45	11.62	10.23	13.18	30.73
Glutamic acid	113.42	95.53	105.08	104.06	99.73	19.19
Glycine	134.15	106.50	81.62	68.04	94.22	43.90
Ornithine	12.63^{b}	9.62^{b}	12.65^{b}	15.40^{bc}	21.17^{d}	29.20
Proline	55.73	49.50	47.52	49.01	53.72	28.26
Plasma urea, mg/100 ml						
	24.57^{bd}	21.55^{b}	21.39^{b}	21.61^{b}	29.79^{d}	20.61

* Coefficient of variation (%) was calculated from the error mean squares.

The footnotes of statistically significant differences are similar to those described in Table 20.

SECTION IV: DISCUSSION

A. EXPERIMENT I

Sow Productivity

Several researchers (Rippel et al, 1965a; Pond et al, 1968a, 1969; DeGeeter et al, 1972) have shown that gilts fed extremely low protein intakes (9-55 g) were not significantly affected in terms of number or weight of pigs born. Diets with cereal as the sole source of protein for pregnant sows have been found to be adequate for maintaining litter size and birth weight (Boaz, 1962; Baker et al, 1970b,c; Hesby et al, 1970a, 1972; Frape et al, 1971; Hawton, and Meade, 1971) and the results of the current study support these observations.

Gilts fed all-maize diets gained less during gestation than gilts fed opaque-2 maize or maize-soybean meal diets (Baker et al, 1970b,c; Hawton and Meade, 1971; Hesby et al, 1970a). Hesby et al, (1972) showed that 0.2% lysine added to normal maize tended to increase sow weight gains during gestation. However, the results showed that sows fed normal maize supplemented with lysine did not gain as much as the opaque-2 maize or maize-soybean meal diets. It indicated that the addition of lysine alone would not completely overcome the amino acid deficiencies of normal maize for pregnant sows. Using nitrogen balance, Allee and Baker (1970) showed that lysine and tryptophan, respectively, were the first and second limiting amino acids in normal maize fed during gestation. It was found that threonine became the first limiting amino acid in barley-based diet after achieving adequacy of lysine for growing pigs (Fuller, Livingston and Mennie, 1974; Taylor, Cole and Lewis, 1974). According to the results of numerous experiments (Eyless, 1959; Lodge, Elsley and MacPherson, 1966, Elsley et al, 1968; Lodge, 1969, Frape et al, 1971; Holden et al, 1971; Frobish, Steele and Davey, 1973), it is generally considered that a gestation gain of about 20 kg is required for normal reproductive performance in sows. This was nearly attained by sows in the current investigations which received 203 g daily protein per head during gestation. It may be possible to enhance the sow gestation gain to over 20 kg if the pregnant sow is fed on a barley-based diet supplemented with the limiting amino acids.

Elsley and MacPherson (1966) indicated that some maternal weight loss (5 kg) of sows occurred during lactation when given daily protein intakes similar to those recommended by the ARC (1967). This occurred in our sows fed the high lysine control diet. Thus, net weight gain of the sow from the first parity to the second was about 10 to 15 kg. Sow weight loss during lactation was not significantly affected by lysine supplementation of the low lysine basal diet. This agrees with the findings of Lewis and Speer (1973). Sows given the basal or supplemented diets lost about 15 kg of body weight during 6 weeks of lactation period. Thus, net sow weight gain from one reproductive cycle to the next was approximately zero. Elsley (1972) has suggested that sows gaining between 12 and 15 kg from cycle to cycle for at least the first 4 parities would be a reasonable indication of nutritional adequacy.

Dietary lysine had a marked effect on weight gains of the litters. In the present experiment, pig gains increased with increasing milk yield and quantities of milk solids, protein and energy in both parities. It appeared that the low lysine basal diet supplemented with up to 0.59% dietary lysine improved the amino acid balance and markedly increased pig gains and sow milk production. However, the litters from sows receiving 0.79% lysine gained slightly more weight than those from sows receiving 0.59 and 0.69% lysine.

Limited data have been reported on the influence of levels of dietary protein and amino acids on sow milk composition. A sharp effect of dietary lysine and protein on total solids, protein, fat and energy of milk was found in this experiment. This is broadly in agreement with the experiments of Greenhalgh (1972) and Lewis and Speer (1973). However, Elliot et al, (1971) and Mahan et al (1971c) found no significant difference in milk composition of sows fed several protein levels, although Mahan et al (1971c) found that albumin was reduced as dietary protein level decreased.

The energetic efficiency of sow milk production was calculated from the gross energy of the milk secreted and the digestible energy intake of the sows. Allowance was applied in these calculations for sow weight loss, on the assumption that 1.0 kg of live weight loss was equivalent to an intake of 30.5 MJ of digestible energy (Bowland, 1967). The efficiency of conversion of dietary protein into milk protein was also calculated using a value of 0.15 kg tissue protein/kg sow weight loss (Vanschoubroek and Van Spaendonck, 1973; Whittemore and Elsley, 1976). From the estimates in Table 24 it can be seen that the energetic efficiency of milk yield and the efficiency of utilization of dietary protein for milk protein synthesis increased from 0.39 to 0.59% dietary lysine, and remained fairly constant thereafter. The sows receiving the supplemented diets had considerably higher efficiencies of protein conversion into milk protein than those receiving the high lysine control diet. It could be that lysine supplementation improved protein utilisation in the low lysine basal diet. The sows given the high lysine control diet had a considerably greater energetic efficiency of milk secretion than the sows given the basal or supplemented diets. It would appear that a barley-based diet supplemented with additional lysine could still have other limiting amino acids which lower milk yield in sows.

TABLE 24

Effect of dietary lysine on estimated energetic efficiency for milk production and on estimated converting efficiency of dietary protein into milk protein(*).

Parameter	Treatment Groups and Dietary Lysine					
	L. B. 0.39%	+ 1 0.49%	+ 2 0.59%	+ 3 0.69%	+ 4 0.79%	H. C. 1.06%
			"PARITY 1"			
Energetic Efficiency of Milk Production, %	26.0	29.0	31.7	30.4	30.6	42.7
Dietary Protein Efficiency of Milk Production, %	40.7	46.7	50.9	48.4	47.3	37.0
			"PARITY 2"			
Energetic Efficiency of Milk Production, %	22.4	25.9	32.2	31.0	28.8	42.8
Dietary Protein Efficiency of Milk Production, %	32.5	38.5	49.2	47.9	45.0	35.6

(*) Efficiency calculation was as follows:

$$\frac{\text{Milk energy or milk protein}}{\left(\begin{array}{l}\text{DE intake + sow weight loss}\\ \text{in terms of energy}\end{array}\right) \text{ or } \left(\begin{array}{l}\text{Protein intake + sow weight loss}\\ \text{in terms of protein}\end{array}\right)}$$

Nitrogen Metabolism

Nitrogen Balance of Pregnant Sows

In this experiment, the pregnant sows receiving the low protein diet (barley-based) retained about 9 g nitrogen daily, which is slightly greater than that found by Allee and Baker (1970) or Hesby et al (1970b). If nitrogen needs for the products of conception and for uterine and mammary growth are estimated at 3.5 g per day (Elsley 1966a; Elsley, 1967), and nitrogen needs for cutaneous losses are estimated at 1 g daily (Baker et al, 1966b; Elsley and MacPherson, 1972), there remains only 4.5 g of the 9 g nitrogen retained daily during gestation for growth of pregnancy anabolism for the sows. This is considerably less retained nitrogen than the maximal nitrogen retention data from several researchers (Rippel et al, 1965b; Miller et al, 1969). Elsley et al (1966b,c) indicated that the pregnant gilt fed 175 g crude protein daily retained in excess of 5-6 g N/day throughout pregnancy to achieve normal development of the uterus and its contents, and of the mammary gland. However, our sows produced normal number and normal birth weight of pigs, and had a net body weight gain of 16.5 kg.

Nitrogen Balance of Lactating Sows

Nitrogen retention (excluding milk nitrogen), retained nitrogen as % total nitrogen intake and biological value in the present study were significantly improved by increasing dietary lysine level up to 0.59%. These findings are in good agreement with the responses for litter gain, milk yield and composition described above. The results of nitrogen balance in our experiment agree with the findings of Kracht (1964) and Lewis and Speer (1973). Positive nitrogen balance was achieved in our sows given a daily intake of 540-580 g CP containing 31-34 g lysine. This daily protein intake is considerably less than the ARC recommendation for lactating sows (1967). Also, it is lower than the results of MacPherson et al (1969), Mahan et al (1971a,b), who have found that lactating sows require 750-800 g crude protein per day to maintain positive nitrogen balance and adequate milk production. However, Ganguli et al (1971) reported that lactating sows fed 420 g crude protein daily were in positive nitrogen balance, but this response was associated with low milk yield. It is apparent that the measurement of protein requirement for lactating sows by nitrogen balance is very dependent upon the quality of dietary protein and on milk yield.

Digestibility of Essential Amino Acids by Sows

Measurement of the amino acid content in feedstuffs gives information on protein quality of the feedstuff for monogastric animals. However, the digestibility of amino acids may vary significantly among different feeds. The term of availability of amino acids has been defined by De Muelenaere, Chen and Harper (1967) as that portion of amino acid present in a protein which is used for growth, development and maintenance of an aminal insofar as it is dependent on the digestibility of the protein, the presence of enzyme inhibitors and enzyme-resistant peptide linkages, and rate of release of amino acid in the intestinal tract.

For pigs, lysine is the most limiting amino acid in many foods of plant origin, especially cereal grains. With consideration of lysine supplementation to diets in which lysine is limiting, it is important to obtain an accurate estimation of its digestibility in these diets in order to interpret 'digestible' amino acid requirement. However, there is very little published data about the digestibility of amino acids in sow diets.

Lysine, isoleucine and valine were the least digestible essential amino acids in the low lysine basal diet (barley-based) for sows in this experiment. According to Sauer, Givannetti and Stothers (1974), the relatively high concentration of cereal lysine in the cereal bran, which is not effectively broken down in monogastric animals, might be responsible for its low digestibility. Apparent digestibility of lysine, methionine and threonine were 77 to 82%, and close to the apparent nitrogen digestibility of 79%. The digestibility of lysine from barley, which is an important constituent of diets for sows, varies considerably between 57 and 77% for growing pigs (Eggum, 1967; Meier, Poppe and Wiesmüller, 1970; Sauer et al, 1974).

Plasma Free Amino Acids

Effect of Time Post-feeding on Plasma Free Amino Acid Concentrations of the Lactating Sow

There is little published data about effect of length of blood sampling time after feeding on plasma free amino acid levels in sows. Optimum blood sampling times in breeding sows have not been studied systematically.

Time of sampling blood after a test meal is one of the important factors affecting free amino acid concentrations in plasma (Young and Scrimshaw, 1972). Maximum level of essential amino acids are generally obtained 1 to 2 hours after feeding with growing pigs (Nordstrom et al, 1970; Pick and Meade, 1970; Typpo et al, 1970; Windels et al, 1971; Davey et al, 1973), the return to baseline levels occurring some 2 to 10 hours later (Nordstrom et al, 1970; Pick and Meade, 1970; Typpo et al, 1970; Windels et al, 1971). In this study, the effect of time post-feeding on concentrations of free essential amino acid in plasma of the lactating sow (Figure 2) is similar to the published observations. MacLaughlan and Illman (1967) chose a 16-hour fasting period after feeding, but Harker et al (1968) indicated that 6 hours fasting gave results which most nearly reflected the true requirements of the animals. However, the level of free amino acids in the plasma taken 4 to 6 hours post-feeding reflected differences in dietary patterns of amino acids (Pick and Meade, 1970; Stockland et al, 1970a, 1971; Stockland and Meade, 1970; Lewis and Speer, 1973, 1974a; Sohail et al, 1974). Studying plasma amino acid response curves in lactating sows, Lewis and Speer (1974b) found that postprandial plasma amino acid levels (about 2 hours after just feeding) were more responsive to amino acid intake than fasting level (after a 16 hour fast).

The level of plasma free lysine of the sow fed the low lysine basal diet in this experiment decreased at a relatively rapid rate 2 hours after feeding as compared with other amino acids. According to Typpo et al (1970), this is indicative of a primary limitation of lysine in the diet.

Effect of Dietary Lysine Supplementation on Plasma Free Amino Acid Concentrations of Lactating Sows and Their Progeny

The significant decreases in plasma levels of threonine, phenylalanine, methionine and leucine with increasing dietary lysine concentration reflected efficient utilisation of these amino acids and also indicated that one or more of these amino acids could become limiting. It was found that threonine became the first limiting amino acid in a barley-based diet after ensuring adequacy of lysine (Howe, Jansen and Glifillan, 1965; Fuller et al, 1974; Taylor et al, 1974). In the present study, plasma free lysine levels of lactating sows remained low and fairly constant from 0.39 to 0.49% dietary lysine in both parities, and increased sharply thereafter. The linear and quadratic decline in the total plasma EAA (not including lysine and tryptophan) with increasing dietary lysine shows additional evidence that lysine supplementation in this basal diet improved amino acid

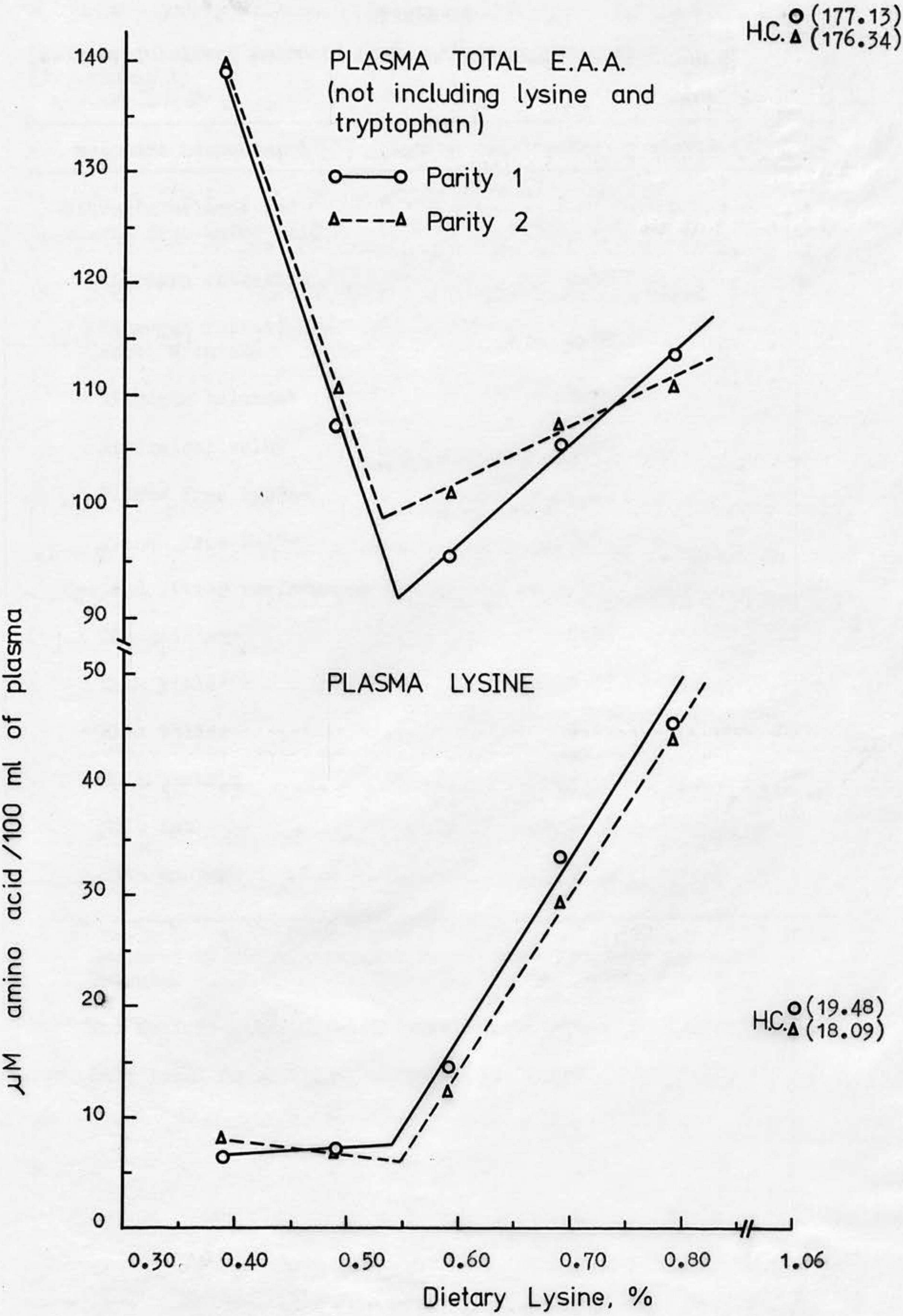

FIG. 3 EFFECT OF DIETARY LYSINE ON PLASMA FREE ESSENTIAL AMINO ACIDS OF LACTATING SOWS (H.C. not included in regression comparison)

TABLE 25

Lysine requirement measured from various response criteria (Experiment I)

Response measurement	Lysine requirement, % air dry feed
Nitrogen balance and plasma free amino acid	
Nitrogen retention	0.55
Nitrogen retention % total N intake	0.59
Nitrogen balance*	0.51
Biological value	0.60
Plasma free lysine	0.55
Plasma free EAA**	0.54
Sow and litter performance	
Pig gain***	0.59
Milk yield***	0.59
Milk solids	0.65
Milk protein	0.64
Milk fat	0.60
Milk energy	0.60

* Measured by calculating the requirement for zero nitrogen balance.

** Not including lysine and tryptophan.

*** Only based on treatment comparison.

balance, and also suggests that lactating sows require between 0.49 and 0.59% dietary lysine (Figure 3).

Plasma amino acid concentrations of piglets were not appreciably influenced by maternal intake of lysine, although there was a tendency to higher lysine level in the plasma of piglets from sows fed 0.39 and 0.49% lysine. Taken together the responses in sow productivity, nitrogen metabolism and plasma free amino acid, indicate that the lactating sow given a 10% crude protein diet requires between 0.49 and 0.59% dietary lysine. In order to ensure the requirement more precisely, the procedures outlined by Lewis and Speer (1973) were applied in the present studies. The lysine requirements evaluated in this way from various responses are shown in Table 25.

The values listed in Table 25 range from 0.51 to 0.65% with a mean of 0.58%. It is a matter of debate which combinations are used but a figure of 0.57-0.59% would appear to the author to be appropriate. In mean terms of daily intake this represents 30.7 g for the lactating gilt and 33.1 g for the lactating sow. If the lysine digestibility of 77% from the low lysine basal diet is taken into account, the 'digestible' lysine requirement is 0.49%.

B. EXPERIMENT II

Sow Productivity

In the present study, the linear and quadratic regressions of sow weight gains on daily protein intakes during pregnancy were significant in both parities (Figures 4, 5 and 6). The optimal daily crude protein intake to gain the maximal sow weights during pregnancy resulted in 325 and 295 g from total weight gains of sows in parities 1 and 2, and in 304 g from net weight gains of the same during pregnancy in parity 1. Taken together the response for both total and net weight

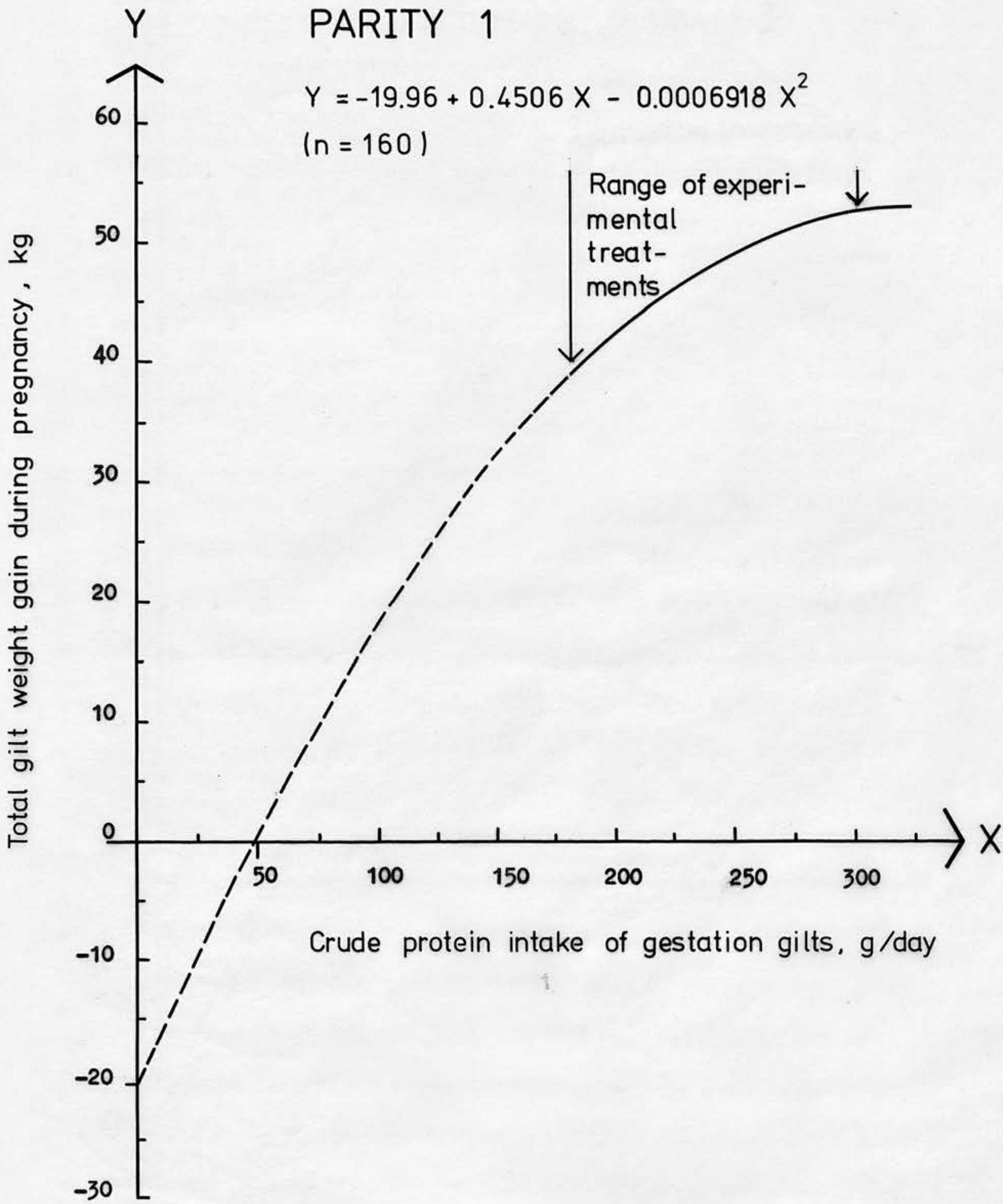

FIG. 4 EFFECT OF PROTEIN INTAKE ON TOTAL GILT WEIGHT GAIN DURING PREGNANCY

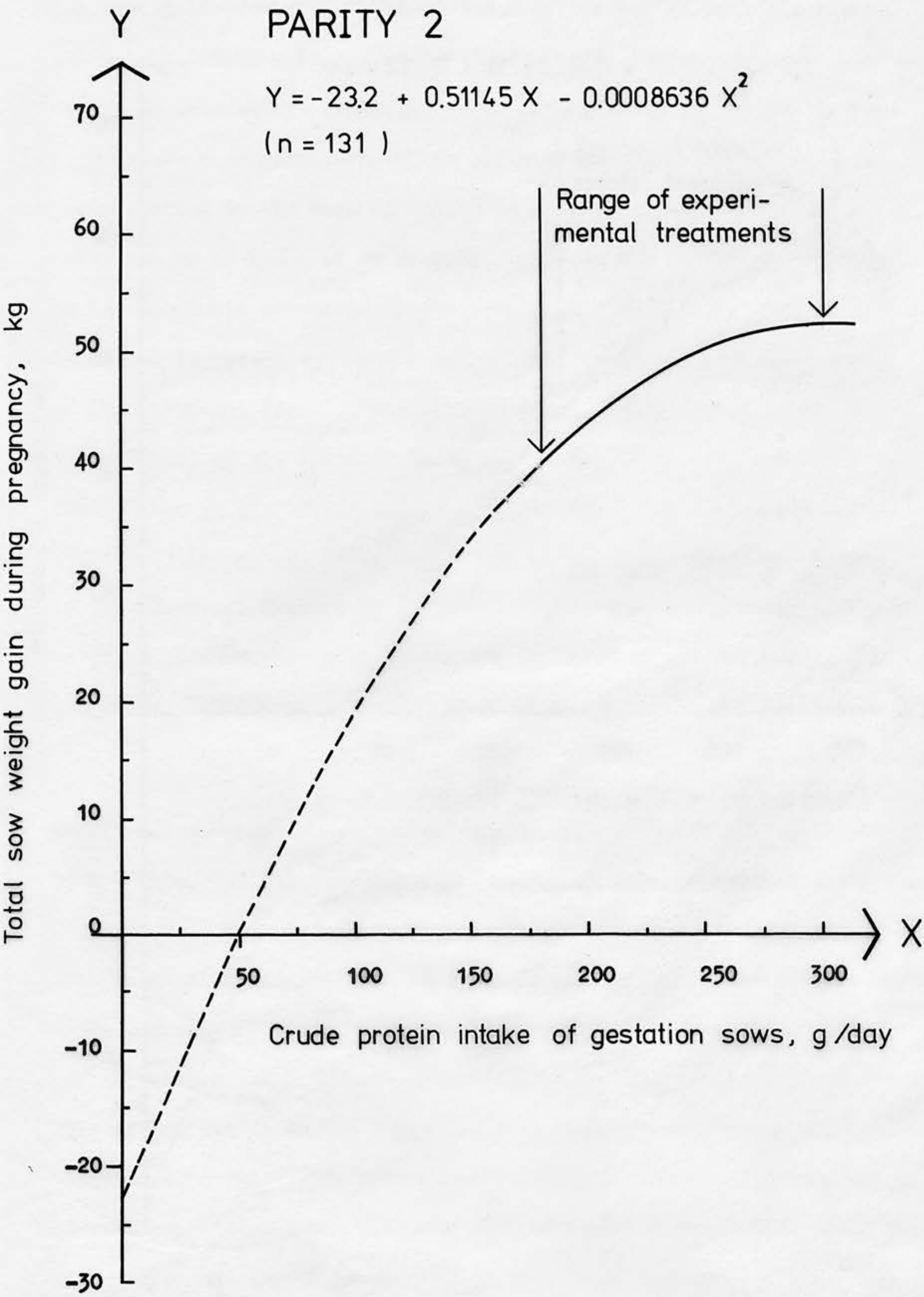

FIG. 5 EFFECT OF PROTEIN INTAKE ON TOTAL SOW WEIGHT GAIN DURING PREGNANCY

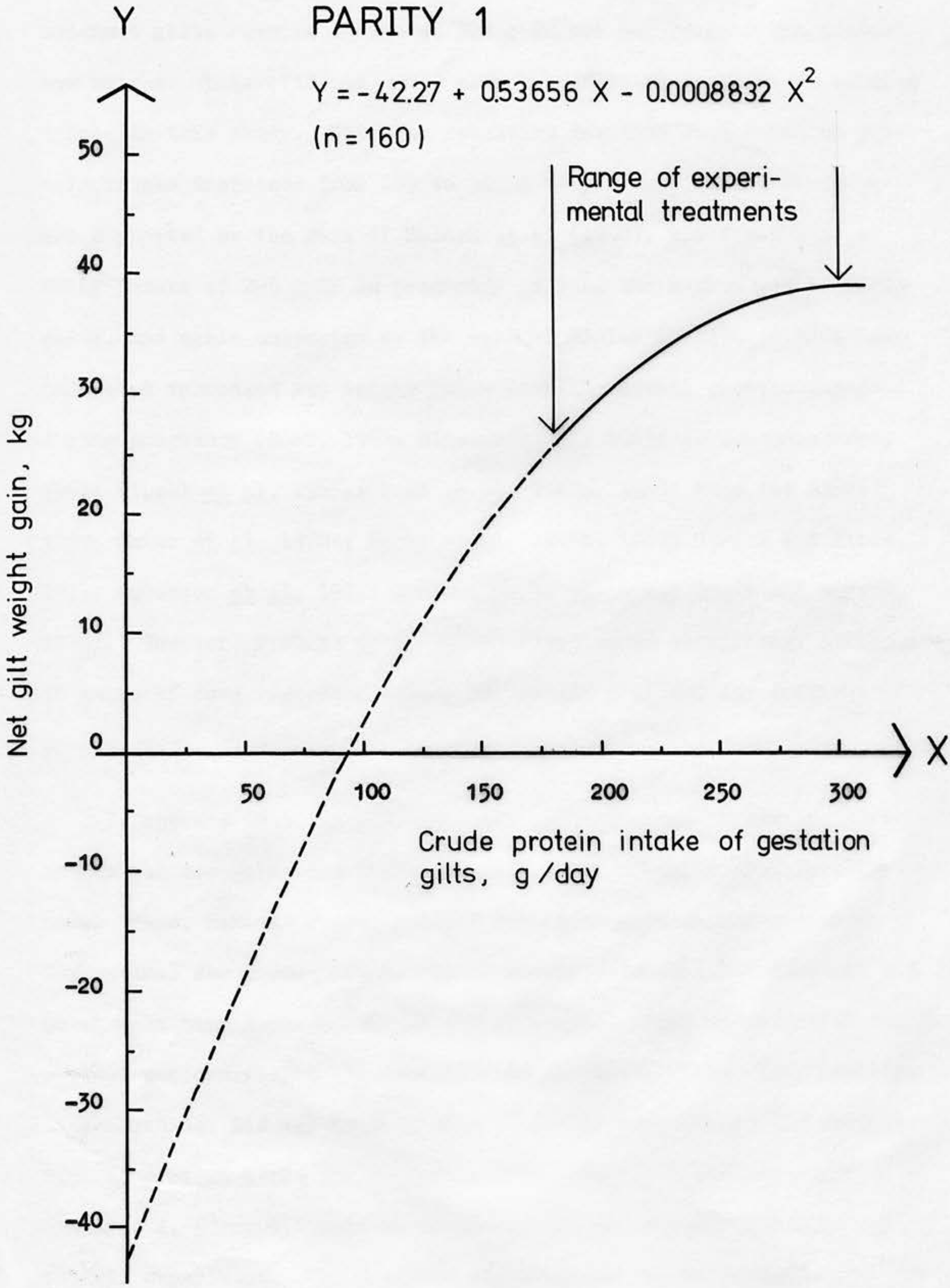

FIG. 6 EFFECT OF PROTEIN INTAKE ON NET GILT WEIGHT GAIN DURING PREGNANCY

gains of sows during pregnancy in both parities, indicate that the pregnant gilts require a mean of 308 g CP per day to gain the maximal sow weight. This evidence could also be reflected by nitrogen balance trials in this study. Nitrogen retention resulted in maximum as protein intake increased from 289 to 315 g CP per day. These findings are supported by the work of Holden et al (1968), who found that a daily intake of 295 g CP in pregnancy yielded the maximal sow weight gains, and again supported by the work of Elsley (1973). Others have indicated increased sow weight gains with increasing protein intakes during pregnancy (Boaz, 1962; Clawson et al, 1963; Salmon-Legagneur, 1963; Rippel et al, 1965a; Pond et al, 1968a, 1969; Pike and Boaz, 1969; Baker et al, 1970c; Hesby et al, 1970a, 1972; Hawton and Meade, 1971; DeGeeter et al, 1972; Greenhalgh et al, 1974; Mahan and Mangan, 1975). However, Frobish et al (1966) reported no significant difference in gains of sows receiving either 182 or 362 g CP per day during pregnancy.

It appears that the protein needs for the pregnant sow, measured by maximal sow weight gain, inevitably leads to a higher protein allowance. Thus, maximal weight gain of gestation sows is not necessary for optimal sow productivity. It is generally considered that net and total gestation gains of 30 and 45 kg, respectively, are required for optimal performance of sow productivity during the first four parities (Vanschoubroek and Van Spaendonck, 1973). If this is so, the prediction of protein needs for gestation sows from the regression lines (Figures 4, 5 and 6) could be found between 200 and 220 g CP per day in this experiment. The pregnant sow received the 9% CP diet with both lysine and tryptophan additions at a daily protein intake of 180 g resulted in 33 and 46 kg of net and total weight gains, respectively. It suggests that protein intake could be reduced to the marginal level providing the adequacy of amino acids is ensured.

Extrapolated regression curves of total sow weight gain on daily protein intake (Figures 4 and 5) reveal that the pregnant sow requires 50 g CP per day for maintenance. This evidence is in good agreement with the work of Rippel _et al_ (1965b) and DeGeeter _et al_ (1972), who resulted in 55 and 45 g CP per day, respectively. It can be seen from Figure 6 that the pregnant sow requires about 94 g CP per day to farrow a litter of piglets and to maintain itself at constant live weight. Thus, a daily intake of 44 g CP could be in excess for the growth of fetus and membranes. If the biological value of the dietary protein is 60% and the digestibility is 80%, then the daily nitrogen retention will be 3.4 g for the growth of fetus and membranes. This result is supported by the studies of Elsley _et al_ (1966a, 1967), who reported that nitrogen needs for the products of conception, for uterine and mammary growth are estimated at 3.5 g per day. The number of pigs born (total and live) and birth weight in this experiment were not affected by the gestation or lactation treatments. As indicated by a number of workers (Stevenson and Ellis, 1957; Boaz, 1962; Clawson _et al_, 1963; Rippel _et al_, 1965a; Holden _et al_, 1968; Pond _et al_, 1968a, 1969; Baker _et al_,1970b,c, 1974; Pike and Boaz, 1969; Hesby et al, 1970a, 1972; Frape _et al_, 1971; Hawton and Meade, 1971; Elsley _et al_, 1971, 1973; Greenhalgh _et al_, 1974; Mahan and Mangan, 1975), the amount of protein in the gestation diet, expressed either in g consumed or a percent of the diet, is not an important factor in affecting litter size or birth weight.

The results of the current experiment and of other published studies (Baker _et al_, 1970b,c; Hesby _et al_, 1970a, 1972; Hawton and Meade, 1971) showed that the pregnant sow given the maize diet as the main source of protein had decreased litter size at weaning. Litter weight at weaning was also depressed by maternal feeding of the maize diet.

The pregnant sows fed the 9% CP diet with the addition of 0.2% L-lysine and 0.05% L-tryptophan had litter sizes and litter gains at weaning which were similar to those from sows fed the 11% or higher CP levels. Thus, amino acid composition of the diet fed during gestation appears to be of some importance in promoting normal early postnatal performance of the progeny. Allee and Baker (1970) have demonstrated that supplementation with both lysine and tryptophan improvesthe protein utilization of a maize diet.

The pregnant sow given the 11% CP diet at a daily intake of 220 g CP gained litter weight at weaning as comparable to those sows given higher protein diets. Based on these responses, the 11% CP diet containing 0.4% lysine or in terms of daily intake 220 g CP is adequate for the pregnant sow. This finding is supported by the results of Frobish et al (1966), Elsley (1969, 1972), Baker et al (1970b,c, 1974), Frape et al (1971), Elsley and MacPherson (1972), Vanschoubroek and Van Spaendonck (1973), and Whittemore and Elsley (1976).

An increase in the weaning to effective service interval is an important commercial disadvantage, if associated with the effect of low-protein gestation diets. In this experiment, there was an indication of an adverse effect on the weaning to effective service interval in sows fed the protein diet lower than 13% in the first parity. However, such effects did not appear after later parity except the pregnant sow fed the 9% CP diet with both lysine and tryptophan additions. Several workers (Holden et al, 1968; Baker et al, 1974; Greenhalgh et al, 1974) have reported that the interval between weaning and re-service was not affected by the pregnant sow receiving high quality protein in quantities as low as 180 g per day. Svajgr et al (1970) indicated that the low protein diet had an adverse effect on the breeding regularity by producing anoestrous sows, prolonged oestrous cycles and decreases in ovulation rates. However, their sows were fed a diet containing only 2% CP (36 g per day) in pregnancy and 5% CP in lactation, as compared with sows fed the 17% CP diet in both pregnancy and lactation.

There was no significant evidence of lactation treatment effects on the performance of sow productivity in this experiment. However, supplementating 0.2% L-lysine up to 0.74% of the diet improved the litter gains of sows fed the basal diet during lactation. Whilst litter gains of lactating sows fed the basal diet supplemented with lysine were comparable to those of sows fed the high protein control diet (15% CP). These facts could also be demonstrated by the blood urea and lysine, and by the nitrogen balance in the present studies.

It is suggested that the lactating sow requires 29.6 and 31.8 g lysine per day for the first and second parity, respectively. These findings support the results of Experiment I. These findings are also supported by the results of Baker _et al_ (1970a), Lewis and Speer (1973), Speer (1974), O'Grady and Hanrahan (1975). Based on litter gains, supplementing the basal diet with methionine, or with methionine and tryptophan after ensuring lysine adequacy had no further improvement in litter gains as compared to the basal diet added lysine. These facts were also reflected by the nitrogen retention, and blood urea and lysine in this experiment. Baker _et al_ (1970a), Speer (1974) recommended that the lactating sow required 14.4-15.8 g sulphur amino acids per day, while Ganguli _et al_ (1971) recommended 16 g sulphur amino acids daily for lactating sows. More recently, O'Grady and Hanrahan (1975) also reported that the mature lactating sow required sulphur amino acids not greater than 21.8 g per day. In the studies of Lewis and Speer (1974a), the daily tryptophan requirement for the lactating sow was found to be 3.4 and 4.5 g, based on the blood metabolite and nitrogen balance criteria, respectively. Our lactating sows received 14.4 g sulphur amino acids and 4.4 g tryptophan per day, therefore, no further increase in litter gain was expected.

Nitrogen Metabolism

Nitrogen Balance of Pregnant Gilts

A linear trend of increasing daily faecal nitrogen excretion with increase in dietary protein was observed in this experiment. The result of the current study supports the published observations (Mitchell and Kick, 1927; Armstrong and Mitchell, 1955; Whiting and Bezeau, 1957; Rippel et al, 1965b; and Miller et al, 1969). A value of 2.4 g metabolic faecal nitrogen excretion per kg of dry matter consumed was extrapolated from the regression line (Figure 7). This value was in broad agreement with those of Armstrong and Mitchell (1955), and Whittemore and Elsley (1976), but higher than those of Vanschoubroek and Van Spaendonck (1973), and D'Mello, Peers and Whittemore (1976). However, the faecal nitrogen loss is very much dependent upon the fibre content in a diet fed the pig (Rerat, 1972; Whittemore and Elsley, 1976). A value of 1.2 g endogenous urinary nitrogen per day was extrapolated from the regression line at zero daily N intake (Figure 8). This value was lower than those of Rippel et al (1965b), Baker et al (1966a), and Whittemore and Elsley (1976) but higher than the value of 0.41 g obtained by Miller et al (1969). However, Forbes, Vaughan and Yohe (1958), and Rippel et al (1965b) reported that data for urinary nitrogen excretion were best described by a curvilinear regression. Millward, Garlick, James, Sender and Waterlow (1976) also indicated that rats fed the protein free diet decreased the rate of protein turnover compared with those fed the high protein diet.

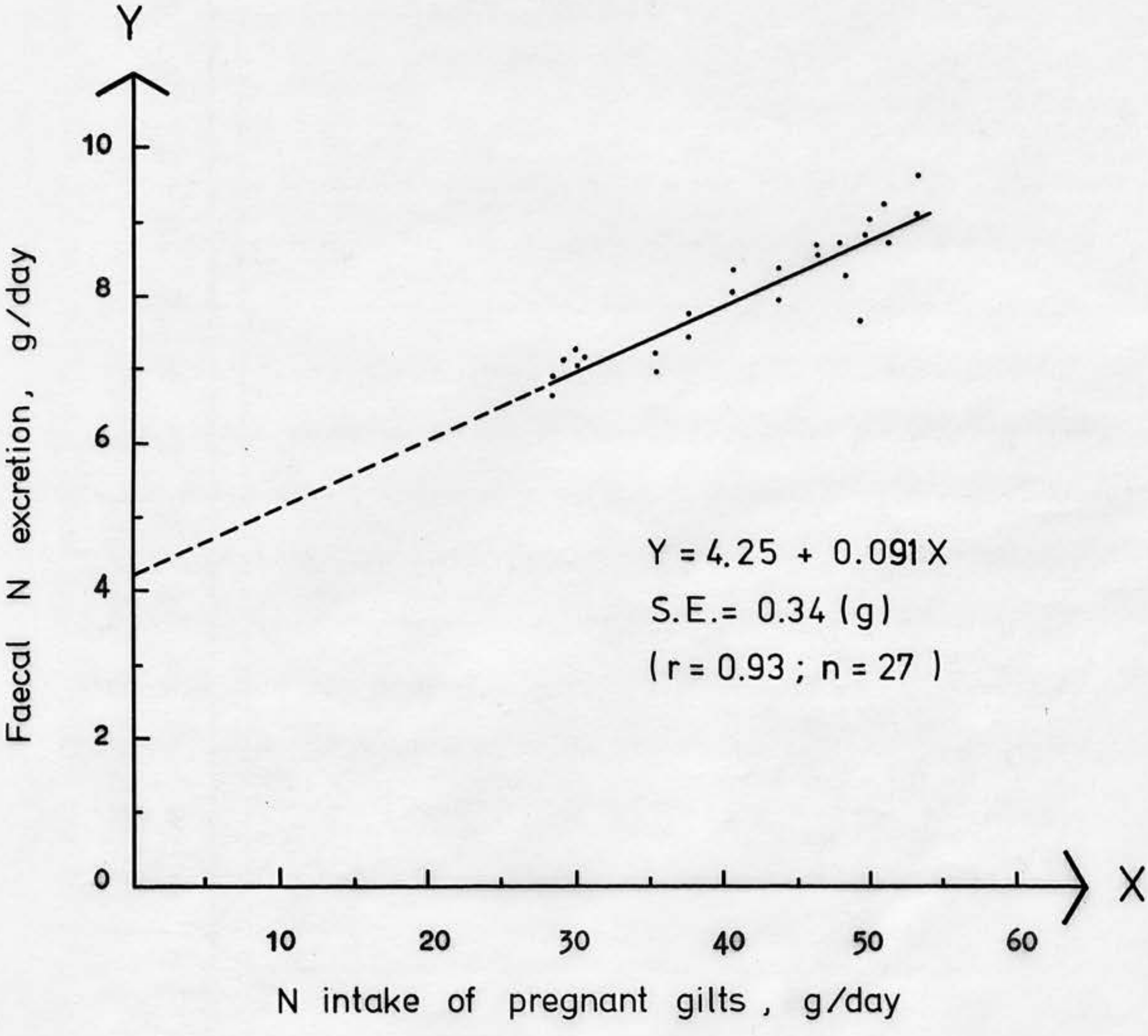

FIG. 7 RELATIONSHIP BETWEEN N INTAKE OF PREGNANT GILTS AND THEIR FAECAL N EXCRETION

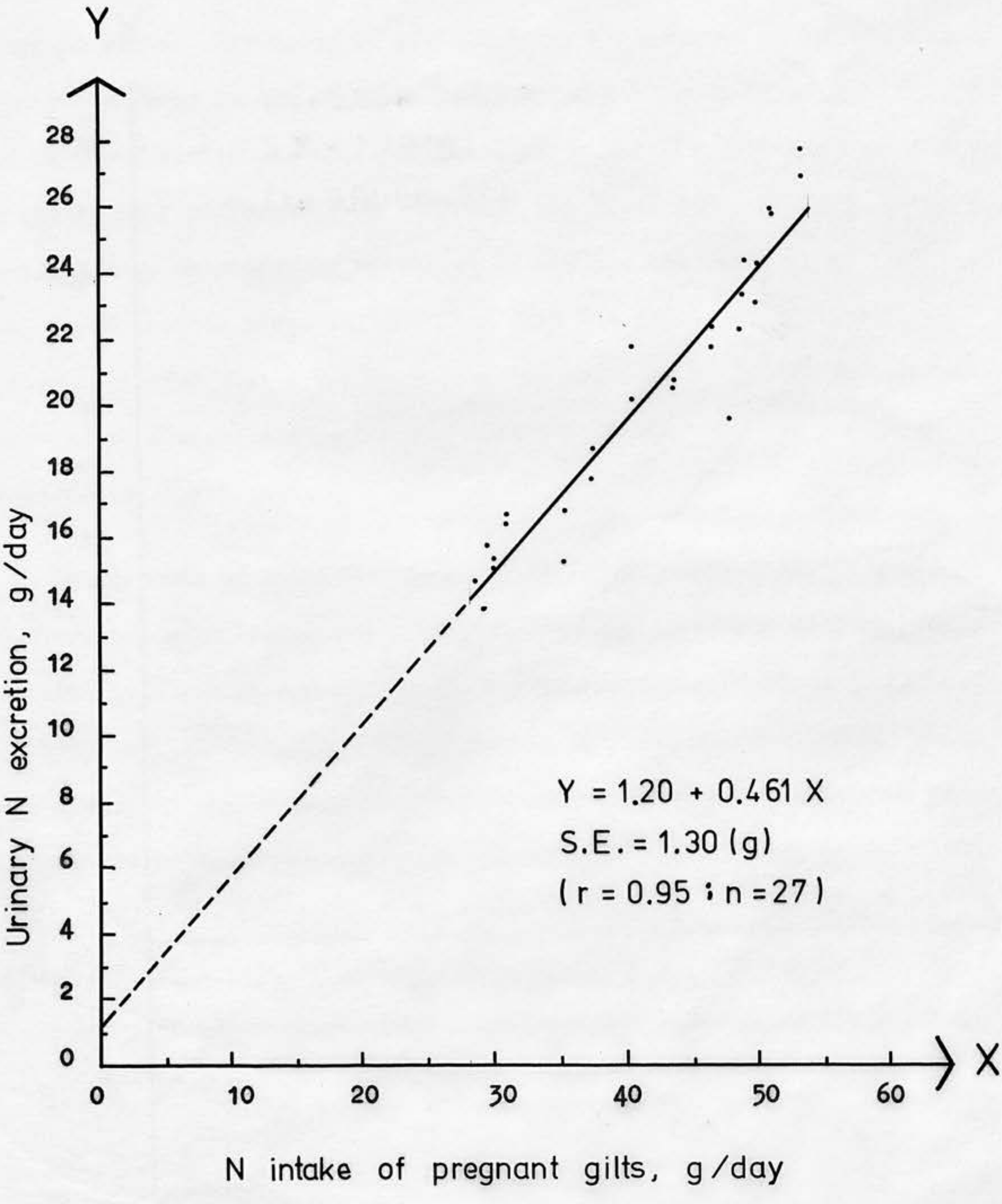

FIG. 8 RELATIONSHIP BETWEEN N INTAKE OF PREGNANT GILTS AND THEIR URINE N EXCRETION

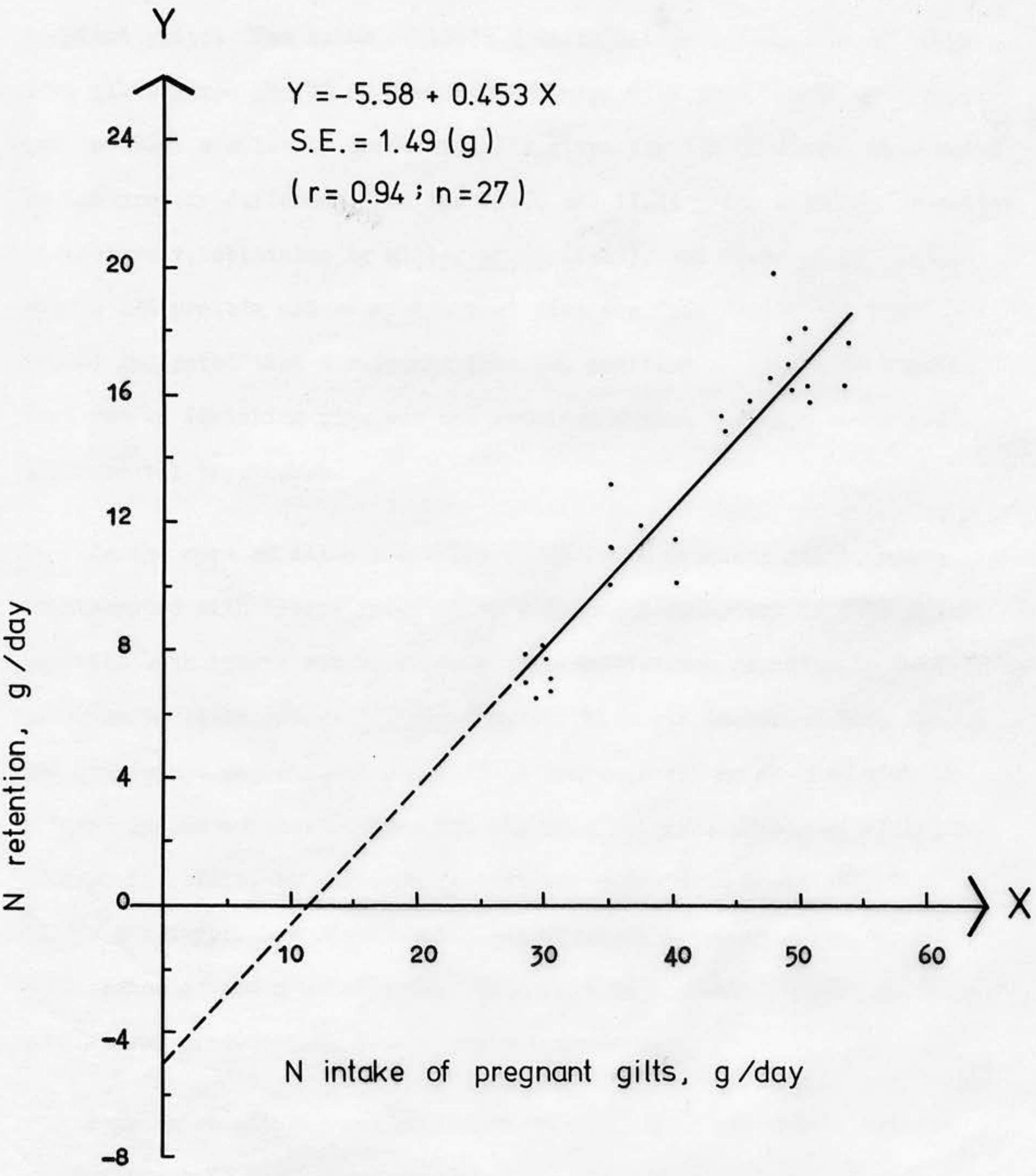

FIG. 9 RELATIONSHIP BETWEEN N INTAKE OF PREGNANT GILTS AND THEIR N RETENTION

Supplementation of the 9% CP diet (fortified maize diet) with both 0.2% L-lysine and 0.05% L-tryptophan increased nitrogen retention by 47% in pregnant gilts. The value of 10.75 g daily nitrogen retention of pregnant gilts given the 9% CP diet supplemented with both lysine and tryptophan is about similar to those of gilts given the 11% CP diet. This value is not greatly different from the 12.30 and 11.41 g/day nitrogen retention, respectively, obtaining by Miller et al (1969), and Hesby et al (1970b), when a 12% protein maize-soybean meal diet was fed. Gallo and Pond (1968) indicated that a response from the addition of lysine to a maize diet fed to finishing pigs was not obtained unless the diet contained supplemental tryptophan.

In the work of Allee and Baker (1970) with pregnant gilts, maize supplemented with lysine resulted in a nitrogen retention of 9.98 g/day, and with both lysine and tryptophan supplementations resulted in further increase to 11.18 g/day. Opaque-2 maize, with its increased both lysine and tryptophan contents is superior to conventional maize diet with or without lysine supplementation for the pregnant gilt (Hesby et al, 1970b, 1972). Therefore, it might suggest that a maize diet containing both lysine and tryptophan supplementations would be quite adequate for performance of sow productivity. This fact is supported by the performance of sow productivity in the present studies.

Regression of nitrogen retention on daily nitrogen intake (excluding Treatment 2) was linear (Figure 9). Although a plateau was not achieved, daily nitrogen retention was increased by only 1.1 g as daily protein intake increased from 289 to 315 g. The increase between any other two adjacent intake levels was at least 4.3 g. This indicates that 289 g of daily protein intake is near the minimal requirement for maximal nitrogen retention. This evidence is in good agreement with the results of Miller et al (1969) but in contrast to those of Rippel et al (1965b), who found maximal nitrogen retention of the pregnant gilt obtained at 230 g of crude protein intake (12.5% CP). Elsley (1973, 1976) has indicated that the gilt mated at 105-120 kg live weight do not normally reach mature weight until the third or fourth parity. Thus, the pregnant gilt may tend to increase protein intake, in an attempt to grow up to mature size.

When a number of workers (Clawson et al, 1963; Frobish et al, 1966; Holden et al, 1968; Elsley, 1969, 1972; Baker et al, 1970c, 1974; Elsley et al, 1971; Frape et al, 1971) used the performance of sow productivity as the response criteria, a daily crude protein intake of 200 g was considered to be adequate for pregnant gilts. Using factorial approach, Vanschoubroek and Van Spaendonck (1973), and Whittemore and Elsley (1976), estimated that the pregnant sow also required about 210 g CP per day, by carefully selecting calculation data and taking new attitudes to growth of maternal tissue. It appears that the protein need for the pregnant sow measured by maximal nitrogen retention inevitably leads to a higher protein allowance. Thus, maximal nitrogen retention of gestation sows is not necessary for optimal performance of sow productivity. The prediction of protein needs for gestation sows from the regression line (Figure 9) at 9 and 11 g nitrogen retention, which is considered as adequate for normal and optimal performance of pregnant sows, results in between 200 and 230 g CP per day.

It can be seen from Figure 9 that a nitrogen intake equivalent to 78 g crude protein (3.9% dietary protein) per day appears to be in excess of maintenance. Rippel et al (1965b) found that 50 g crude protein per day (3% CP diet) was in excess for maintenance of pregnant sows. While Whittemore and Elsley (1976) suggested that the mature sow needed a 5% CP diet for maintenance. The result of this study is broadly in agreement with their findings.

The 9% CP diet fed to pregnant gilts decreased nitrogen retention as % of total N intake as compared with those fed the lysine and tryptophan supplemented diet, or those fed the higher protein diets. Measured N retention as % total N intake, pregnant gilts increased protein utilization with increasing dietary protein level from 9% to 13% , and slightly decreased at 15% CP. It suggests that the dietary protein requirement for pregnant gilts is between 13 and 15% CP. The 9% CP diet supplemented with lysine and tryptophan resulted in nitrogen retention as % total N intake comparable with the 13 and 15% CP diets. It is an additional evidence of improving the amino acid balance in the 9% CP diet.

Nitrogen Balance of Lactating Sows

The basal diet supplemented with lysine increased nitrogen retention and nitrogen retained as % total N intake. These evidences indicate that the supplemental lysine improves the amino acid balance in this diet. Supplementing the basal diet with methionine, or with methionine and tryptophan after ensuring lysine adequacy had no further increases in nitrogen retention, and nitrogen retained as % of total N intake. It suggests that lysine is the first limiting amino acid in the basal diet, but methionine and/or tryptophan are not the limiting amino acids in this diet after providing lysine adequacy. These facts are also reflected by the results of litter gain in this study. The results of Lewis and Speer (1973), and the author's previous experiment (Experiment I) showed that the lactating sow given 29-31 g of lysine intake per day resulted in maximal nitrogen retention. Thus, our lactating sows received 33 g lysine per day providing 4.5 kg of the basal diet supplemented with lysine meet the requirement as expected.

Plasma Free Amino Acids and Urea

Pregnant Gilts

The dietary additions of lysine and tryptophan to the 9% CP diet decreased the plasma urea and plasma free amino acids except lysine. However, plasma free lysine concentrations increased/

in response to these additions. It provided evidence that both lysine and tryptophan supplementations in this 9% CP diet improved amino acid balance. Sharply increasing the plasma lysine with lysine supplementation of the 9% CP diet suggests that pregnant gilts require dietary lysine less than 0.48% (9.6 g per day). Plasma lysine remained at a low and steady level from those pregnant gilts fed the 9% CP diet (0.28% dietary lysine) up to the 11% CP diet (0.40% dietary lysine) and increased sharply thereafter. Therefore, it suggests that lysine requirement for gestation gilts is met or exceeded between 0.40 and 0.48% dietary lysine (8.0 and 9.6 g per day). Salmon-Legagneur and Duee (1972) and Duee and Rerat (1974, 1975) showed that lysine requirement for pregnant sows was 0.44% and 0.43% dietary lysine (8.8 and 8.6 g per day) respectively, based on blood plasma urea, nitrogen retention and reproductive performance data. Recently, Woerman and Speer (1976) concluded that a level of 0.43% dietary lysine (7.8 g per day) would satisfy the lysine requirement for pregnant sows, based on plasma free amino acid and urea, and reproductive performance criteria. The results of this experiment are in due accord with their findings.

Lactating Sows

The declines of plasma urea and amino acid concentrations of lactating sows fed the basal diet (12.5% CP, 0.54% lysine) supplemented with lysine reflected efficient utilization of these amino acids in this diet, and also indicated that lysine supplementation of the basal diet improved amino acid balance. Based on plasma urea, supplementing the basal diet with methionine, or with methionine and tryptophan after ensuring lysine adequacy had no further improvement in protein utilization. It suggested that methionine and/or tryptophan were not the limiting amino acids in the basal diet after ensuring lysine adequacy. As expected our lactating sows fed the basal diet , providing 14.4 g sulphur amino acid and 4.4 g tryptophan per day, had met their requirements. Plasma lysine increased sharply as the basal diet was supplemented with lysine indicating that the daily requirement of 29.6 g was met or exceeded for lactating gilts. This result is in agreement with the findings of litter gain and nitrogen balance in the present experiment, and the previous experiment (Experiment I). In lactating sows fed a lysine adequate basal diet, plasma lysine concentrations were enhanced by the additions of methionine or methionine and tryptophan, thus indicating that the latter two amino acids were not limiting in these diets.

C. IMPLICATIONS OF RESULTS TO COMMERCIAL SOW MANAGEMENT IN TAIWAN

Pig production is of great importance to Taiwan, and its annual production value is of the second place, next to rice production, in total value of agricultural output. Taiwan currently produces some 4.5 million finishing pigs per year. The total number of sows and gilts is about three hundred thousand. The present feeding systems of breeding sows are as follows (Chen, Lai, Su and Yeh, 1973; Yeh, Chen and Rai, 1975):

Gestation or Lactation	Duration, days	Daily Feed Intake, kg/Head	Daily CP Intake, g/Head	Daily DE Intake, Mcal/Head
Weaning to mating	10	2.5	350	7.9
The first two-thirds of pregnancy	80	2.0	280	6.3
The last one-third of pregnancy	34	2.5	350	7.9
Average		2.15	300	6.8
Lactation	35	3.5	560	11.0

Currently, many farmers have adopted 4 to 5 week weaning systems under practical conditions in Taiwan.

Taiwan relies to a large extent on imported feedstuffs, mainly maize and soybean, but also other feed grains and protein feeds in smaller quantities. With the present trend of increased prices of imported feedstuffs - a trend which may be reversed to some extent in the short term, but which in the long term is expected to continue - the saving of protein consumption or improving protein utilization by pigs is greatly important to Taiwan. A daily intake of 3.5 kg feed has been fed to the lactating sow in Taiwan, it would be too low energy allowance to produce adequate milk for piglets. Thus, the sows would use a great part of body weight gained during pregnancy to supply nutrients for milk production. It has been shown that the overall efficiency of feed utilization by the sow would be greater if both weight gain during pregnancy and weight loss during lactation were reduced (Salmon-Legagneur, 1965; Lodge et al, 1966; Bowland, 1967; Parker and Clawson, 1967; Elsley et al, 1968, 1969).

Based on the results from the current studies, an 11% CP diet containing 0.44% lysine is recommended for the pregnant sow given 2.0 kg diet per day under practical conditions in Taiwan. If the prices of lysine and tryptophan are reasonable, a 9% CP diet (maize based) with both 0.2% L-lysine and 0.05% L-tryptophan additions is also recommended for the pregnant sow. In the present studies with a large number of sows shown, a value of 32 g lysine is recommended for the lactating sow fed at a daily intake of 4.5 kg diet containing 15% CP under practical conditions in Taiwan. If the price of lysine is reasonable, a 15% CP of conventional lactation diet can be substituted by a 12.5% CP diet with 0.2% L-lysine supplementation.

The implications of recommendations listed above for subtropical areas such as Taiwan are considerable. If we assume that these standards were adopted nationally, then with a sow population of three hundred thousand the annual increment saving in protein would be 4,300 tons. This could be equated to an amount saving of 9,700 tons soybean meal, or £1.3 million ($ NT 91 million).

D. FUTURE NUTRITIONAL STUDIES WITH SOWS

It is apparent that a great deal of work has been published in the last 5 years which has added to our knowledge of protein nutrition of breeding sows. However, there are a number of areas which would appear to justify immediate experimentation. These will be summarised briefly in the following section.

Relationship between adequate retention of nitrogen and sow weight Change

It is generally considered that the daily retention of 11 g nitrogen in combination with satisfactory sow weight changes is adequate for optimal performance of sow productivity. The sows in the current studies (Experiment I) which received the 10% CP barley-based diet only retained 9 g nitrogen per day but still gained 16 kg of net weight during pregnancy. It may be possible to enhance nitrogen retention to over 11 g and the net gestation gain to over 25 kg if the pregnant sow is fed on a barley-based diet supplemented with the limiting amino acids. Therefore, the limiting amino acids in the barley-based diet for gestation need to be explored in relation to sow weight change.

Balance of amino acids for lactating sows

The lactating sow fed the high lysine control diet based on barley and soybean meal had a considerably greater (10%) energetic efficiency of milk secretion than the sows fed the barley-based diet or supplemented diet (Experiment I). It would appear that a barley-based diet with adequate lysine addition could still have other limiting factors (amino acids and/or energy) which lower milk yield in the sows. These factors should be studied in future programmes.

Based on nitrogen retention, blood metabolites and sow productivity criteria, the 12.5% CP of maize-soybean diet supplemented with methionine, or with methionine and tryptophan after providing lysine adequacy for lactating sows (Experiment II) had no further improvement. It is clear that lysine is the first limiting amino acid in this diet, but methionine and/or tryptophan will not become the limiting factors in this diet after ensuring lysine adequacy. The other limiting factors (amino acids and/or energy) which exist in this diet [redacted] required for exploration in future studies.

Interaction between nutrition and health

Pregnant sows fed the 9% CP diet had the lowest percentage of number of litters weaned as % of total litters farrowed than those fed the other 4 diets. It was also observed that diarrhoea occurred in litters from sows given the 9% CP diet more than the other 4 diets (Experiment II). It would be valuable to investigate the effects of maternal protein deficiency on the concentrations of immuglobulin fractions in sow's colostrum or on the immune response of the progeny in future studies.

Breeding regularity and conception rate

None of the programmes so far undertaken either by the author or by others have satisfactorily studied this approach. Although the results give little indication of results which would cause concern (Experiment II), it is necessary for the doubts expressed by some farmers in relation to breeding regularity and protein or amino acid intake to be subjected to the same scrutiny as that adopted for other productivity traits.

APPENDIX 1

Composition of diets used in Experiment I

Ingredients, %	Pregnancy: Low protein diet	Lactation: Low lysine basal diet (L.B.)	Lactation: High lysine control diet (H.C.)	Creep feed
Barley	88.2	90.7	69.6	38.2
Ground wheat	-	-	-	20.0
Maize flakes	-	-	-	24.0
Wheatings	10.0	7.5	7.5	5.0
Skimmed milk	-	-	-	5.0
White fish meal	-	-	-	7.5
Soybean meal	-	-	20.4	-
Vitamin & mineral supplements	1.8*	1.8*	1.8*	0.3*
Dicalcium phosphate	-	-	0.7	-
Total	100.0	100.0	100.0	100.0
Chemical Analysis (air-dry base)				
Dry matter, %	86.78	86.59	86.18	86.76
Crude protein, %	10.14	10.12	17.34	16.27
Digestible energy, MJ/kg**	12.34	12.59	12.38	13.01
Essential amino acids, %				
Arginine	0.69	0.55	1.38	0.99
Histidine	0.24	0.22	0.51	0.41
Isoleucine	0.35	0.35	0.82	0.60
Leucine	0.75	0.91	1.56	1.37
Lysine	0.41	0.39	1.06	0.82
Methionine + cystine	0.37	0.34	0.62	0.54
Phenylalanine	0.52	0.56	1.01	0.71
Threonine	0.37	0.46	0.96	0.67
Valine	0.52	0.45	0.97	0.79

* See Appendix 2.

** Calculated values except 'low' lysine basal diet.

APPENDIX 2

Vitamin and Mineral Supplements Used in Experiment I

	Gestation and Lactation Diets	Creep Feed
(Supplied the following per kg of diet)		
Vitamin A	7,000 IU	4,000 IU
Vitamin D	500 IU	1,000 IU
Vitamin B_2	2.5 mg	2.0 mg
Vitamin B_{12}	20 μg	4 μg
Active pantothenic acid	8 mg	8 mg
Nicotinic acid	-	10 mg
NaCl	1.6 g	-
Ca	3.3 g	-
Fe	10 mg	100 mg
Co	-	1.5 mg
Mn	70.2 mg	40 mg
Cu	8 mg	10 mg
I	0.13mg	1 mg
P	2.3 g	-
Zn	15.6 mg	100 mg

APPENDIX 3

Composition of Gestation Diets used in Experiment II

Dietary Ingredient, %	1 9% CP	2 (*1)	3 11% CP	4 13% CP	5 15% CP
Maize	83.5	83.2	78.0	72.0	66.5
Soybean Meal	2.5	2.5	8.0	14.0	19.5
Molasses	8.0	8.0	8.0	8.0	8.0
Grass Meal	3.0	3.0	3.0	3.0	3.0
Dicalcium Phosphate	1.8	1.8	1.8	1.8	1.8
Limestone	0.5	0.5	0.5	0.5	0.5
Common Salt	0.5	0.5	0.5	0.5	0.5
Vitamin Premix**	0.1	0.1	0.1	0.1	0.1
Trace Mineral Premix**	0.1	0.1	0.1	0.1	0.1
L-lysine . HCl	-	0.255	-	-	-
L-tryptophan	-	0.051	-	-	-
CHEMICAL ANALYSES (% of air-dry diet)					
Dry Matter	88.91	88.83	89.12	89.00	89.15
Crude Protein	9.20	9.24	11.11	13.28	15.08
Calcium	0.87	0.90	0.81	0.85	0.87
Phosphorus	0.58	0.65	0.60	0.64	0.64
ESSENTIAL AMINO ACIDS					
Arginine*	0.46	0.46	0.51	0.77	0.92
Histidine*	0.22	0.22	0.27	0.32	0.36
Isoleucine	0.30	0.30	0.37	0.53	0.62
Leucine	0.88	0.88	1.13	1.25	1.39
Lysine	0.28	0.48	0.40	0.58	0.76
Methionine	0.16	0.16	0.19	0.23	0.26
Cystine*	0.10	0.10	0.14	0.17	0.21
Phenylalanine	0.44	0.44	0.48	0.63	0.74
Threoine	0.32	0.32	0.36	0.52	0.58
Tryptophan*	0.06	0.11	0.10	0.14	0.18
Valine	0.35	0.35	0.46	0.60	0.72

(*) As 1 + 0.2% L-lysine + 0.05% L-tryptophan.

* Calculated value.

** See Appendix 6.

APPENDIX 4

Composition of Lactation Diets used in Experiment II

Dietary Ingredient, %	1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 H.C.
Maize	75.0	74.7	74.7	74.7	66.5
Soybean Meal	11.0	11.0	11.0	11.0	19.5
Molasses	8.0	8.0	8.0	8.0	8.0
Grass Meal	3.0	3.0	3.0	3.0	3.0
Dicalcium Phosphate	1.8	1.8	1.8	1.8	1.8
Limestone	0.5	0.5	0.5	0.5	0.5
Common Salt	0.5	0.5	0.5	0.5	0.5
Vitamin Premix**	0.1	0.1	0.1	0.1	0.1
Trace Minerals**	0.1	0.1	0.1	0.1	0.1
L-lysine . HCl	-	0.255	0.255	0.255	-
DL-methionine	-	-	0.051	0.051	-
L-tryptophan	-	-	-	0.025	-
CHEMICAL ANALYSIS (% of air-dry diet)					
Dry Matter	88.90	88.49	88.31	88.36	88.20
Crude Protein	12.59	12.53	12.61	12.75	15.08
Calcium	0.86	0.89	0.82	0.88	0.90
Phosphorus	0.59	0.64	0.61	0.63	0.65
ESSENTIAL AMINO ACIDS					
Arginine*	0.69	0.69	0.69	0.69	0.92
Histidine*	0.29	0.29	0.29	0.29	0.36
Isoleucine	0.49	0.49	0.49	0.49	0.62
Leucine	1.19	1.19	1.19	1.19	1.39
Lysine	0.54	0.74	0.74	0.74	0.76
Methionine	0.21	0.21	0.26	0.26	0.26
Cystine*	0.15	0.15	0.15	0.15	0.21
Phenylalanine	0.60	0.60	0.60	0.60	0.74
Threonine	0.49	0.49	0.49	0.49	0.58
Tryptophan*	0.11	0.11	0.11	0.14	0.18
Valine	0.54	0.54	0.54	0.54	0.72

* Calculated value.
** See Appendix 6.

APPENDIX 5

Composition of Creep Feed used in Experiment II

Dietary Ingredient	%
Maize	58.9
Wheatings	5.0
Sucrose	8.0
Dry skimmed milk	10.0
Fish meal	7.0
Soybean meal	10.0
Limestone	0.5
Common salt	0.4
Vitamin premix*	0.1
Trace mineral premix*	0.1
TOTAL	100.

Calculated Nutrient Composition	% of air-dry diet
Crude protein	18.2
Lysine	1.04
Calcium	0.81
Phosphorus	0.73

* See Appendix 6.

APPENDIX 6

Vitamin and Trace Mineral Premixes used in Experiment II

Premix	Gestation and Lactation Diets	Creep Feed
Vitamin Premix (Supplied the following per kg of diet)		
Vitamin A	5,000 IU	8,000 IU
Vitamin D_3	500 IU	1,600 IU
Vitamin B_1	-	2.5 mg
Vitamin B_2	2.5 mg	4 mg
Vitamin B_6	-	0.6 mg
Vitamin B_{12}	15 µg	20 µg
Pantothenic acid	10 mg	12 mg
Niacin	20 mg	30 mg
Folic acid	-	0.2 mg
Vitamin E	15 mg	20 mg
Vitamin K_3	-	2.5 mg
Choline chloride	50 mg	100 mg
Trace Mineral Premix (Supplied the following per kg of diet)		
Co	1 mg	1 mg
Cu	10 mg	10 mg
Fe	50 mg	50 mg
I	1 mg	1 mg
Mn	30 mg	30 mg
Zn	100 mg	100 mg

APPENDIX 7

Preparation of 0.325 w/w% EGA Column Packing

The column packing was prepared by placing 49.8375 g of support material, 80/100 mesh acid-washed Chromosorb G which had been heat-treated for 15 h in a muffle furnace at 600°C, in a 500 ml ridged round bottom flask. 'Nanograde' acetonitrile was added until the liquid level was about 1/4 in. above the support material. Then 0.1625 g of stabilized grade EGA (ethylene glycol adipate) was weighed into a small Erlenmeyer flask, dissolved in acetonitrile, and transferred to the flask containing the support. The flask containing the support and EGA was then placed in a 60°C water bath, and the solvent was slowly removed with a rotary evaporator under partial vacuum over a period of about 45 min. The dry freely-flowing column packing was ready for column preparation.

APPENDIX 8: REASONS FOR DISPOSAL OF SOWS (EXPERIMENT II).

A. LOSSES AND TREATMENTS AT THE END OF PARITY 2

Gestation Treatment Group	Lactation Treatment Group 1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15% CP	Gestation Treatment Effect
1. 9% CP		1	1	1	2	5
2. As 1. + 0.2% L-lys. + 0.05% L-tryp.	1	1		1		3
3. 11% CP	1	1	1	1	1	5
4. 13% CP	2		1		1	4
5. 15% CP	1	1		1		3
Lactation Treatment Effect	5	4	3	4	4	20

B. CAUSES OF LOSSES

No. Sow Loss	Causes
3	Injured (fighting)
2	Not pregnant after remating
2	No apparent signs of heat
7	Lame
2	Ulcer
2	Mastitis
2	Aborted

APPENDIX 9

Effect of Dietary Protein Concentrations and the Supplementation of Synthetic Amino Acids during Gestation and Lactation on Total Gestation Weight Gain (kg) of Sows (Experiment II).

Gestation treatment groups	Parity	Lactation treatment groups				
		1 L. B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15%CP
1. 9% CP	1	34.3	39.9	37.1	38.1	42.4
	2	43.6	39.9	38.4	40.6	36.6
2. As 1 + 0.2% L-lys.	1	43.3	43.8	41.8	48.8	48.3
+ 0.05% L-tryp.	2	51.2	42.9	42.7	47.7	51.6
3. 11% CP	1	47.8	47.3	43.3	47.6	48.4
	2	45.4	44.5	54.2	50.7	46.4
4. 13% CP	1	47.6	50.3	47.9	50.1	50.5
	2	50.7	52.6	49.3	48.6	48.6
5. 15% CP	1	53.8	51.5	51.9	53.0	56.6
	2	47.8	52.2	47.7	52.0	53.6

APPENDIX 10

Effect of Dietary Protein Concentrations and the Supplementation of Synthetic Amino Acids during Gestation and Lactation on Net Gestation Weight Gain (kg) of Sows (Experiment II).

Gestation treatment groups	Parity	Lactation treatment groups				
		1 L. B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15%CP
1. 9% CP	1	21.8	29.3	24.0	26.3	24.6
	2	31.6	26.4	24.6	27.4	22.1
2. As 1 + 0.2% L-lys.	1	31.8	34.1	28.0	33.4	36.0
+ 0.05% L-tryp.	2	39.3	32.1	30.5	33.1	36.0
3. 11% CP	1	34.6	35.1	31.6	36.4	35.1
	2	29.6	30.8	36.5	34.0	33.3
4. 13% CP	1	33.8	36.5	34.8	36.6	38.3
	2	37.7	36.7	36.6	32.6	35.1
5. 15% CP	1	41.0	35.4	38.5	41.5	42.3
	2	33.5	38.9	35.6	39.4	38.1

APPENDIX 11

Effect of Dietary Protein Concentrations and the Supplementation of Synthetic Amino Acids during Gestation and Lactation on Litter Weight (kg) at Weaning (Experiment II).

Gestation treatment groups	Parity	Lactation treatment groups				
		1 L. B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15%CP
1. 9% CP	1	30.7	30.5	31.4	31.7	29.9
	2	46.8	40.1	41.6	43.4	41.5
2. As 1 + 0.2% L-lys.	1	38.9	40.9	40.1	39.1	40.4
+ 0.05% L-tryp.	2	45.7	45.6	47.4	47.8	53.8
3. 11% CP	1	37.1	39.9	39.3	37.9	40.5
	2	48.9	44.6	49.9	50.9	53.0
4. 13% CP	1	39.8	40.8	42.7	43.0	41.0
	2	48.1	58.0	48.4	50.8	53.9
5. 15% CP	1	40.1	49.4	43.0	45.1	44.1
	2	45.0	48.0	49.6	49.1	51.7

APPENDIX 12

Effect of Dietary Protein Concentrations and the Supplementation of Synthetic Amino Acids during Gestation and Lactation on Net Litter Weight Gain (kg) (Experiment II).

Gestation treatment groups	Parity	Lactation treatment groups				
		1 L.B.	2 As 1 + 0.2% L-lys.	3 As 2 + 0.05% DL-meth.	4 As 3 + 0.025% L-tryp.	5 15%CP
1. 9% CP	1	19.2	19.9	20.5	21.1	19.4
	2	31.0	26.0	28.4	28.6	26.7
2. As 1 + 0.2% L-lys.	1	27.0	27.8	27.8	26.9	26.4
+ 0.05% L-tryp.	2	30.1	32.5	32.2	30.4	37.6
3. 11% CP	1	25.1	27.1	26.9	26.6	27.9
	2	31.2	29.3	33.1	35.9	38.0
4. 13% CP	1	26.1	27.6	28.3	29.4	29.2
	2	33.6	39.9	32.9	34.0	36.7
5. 15% CP	1	28.1	35.0	29.4	30.3	30.9
	2	30.8	33.0	33.7	32.5	36.1

APPENDIX 13

Sample of analysis of variance: total litter gain of the first lactation (Experiment I).

Below is a sample copied from the computer "print-out" of analysis of variance and table of means.

Analysis of variance

Source of variance	Degree of freedom	Sum of squares	Mean square	Variance ratio	Significant level
Treatment	5	198.8094	39.76187	2.88	*
Block	5	215.0021	43.00043	3.12	*
Residual	23	316.8894	13.77797		

Treatment mean

Grand mean	L.B.	+ 1	+ 2	+ 3	+ 4	H.C.
57.74	49.86	54.93	59.90	53.70	63.59	64.47

R.S.D. = 8.166 CV = 14.1%

Individual treatment effects (excluded H.C.)	Variance	F	Significant level
Linear trend with lysine	80.067444	5.81	*
Quadratic tendency	0.200271	0.01	N.S.
Residual	13.77797		

APPENDIX 14

Sample of analysis of variance: net litter gain in the second lactation (Experiment II).

Below is a sample copied from the computer "print-out" of analysis of variance and table of means.

Analysis of variance

Source of variance	D.F.	S.O.S.	M.S.	V.R.	Significant level
Pregnancy treatment	4	969.0479	242.2620	5.592	***
Treat.2 vs Others	1	0.0264	0.0264	0.001	N.S.
Linear	1	461.2983	461.2983	10.648	**
Quadratic	1	458.9092	458.9092	10.592	**
Deviation	1	48.8139	48.8139	1.127	N.S.
Lactation treatment	4	289.3381	72.3345	1.670	N.S.
Treat.1 vs Others	1	69.4583	69.4583	1.603	N.S.
Among Others	3	219.8798	73.2932	1.692	N.S.
Pregnancy x Lactation	16	627.5213	39.2200	0.905	N.S.
Block	7	845.1897	120.7414	2.787	**
Residual	139	6022.0742	43.3243		

R.S.D. = 6.58 CV = 20.22%

S.E. = 1.13 Grand mean = 32.55

Least significant difference

at	5%	3.15
at	1%	4.16
at	0.1%	5.36

/contd.

/contd. Treatment means and differences

Gestation treatment	Mean	Difference			
1	28.275				
2	32.576	4.301**			
3	33.476	5.201**	0.900		
4	35.278	7.003***	2.702	1.802	
5	33.151	4.876**	0.575	-0.325	-2.127
Lactation treatment	**Mean**	**Difference**			
1	31.319				
2	32.119	0.800			
3	32.190	0.871	0.071		
4	32.222	0.903	0.103	0.032	
5	35.120	3.801	3.001	2.930	2.898

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